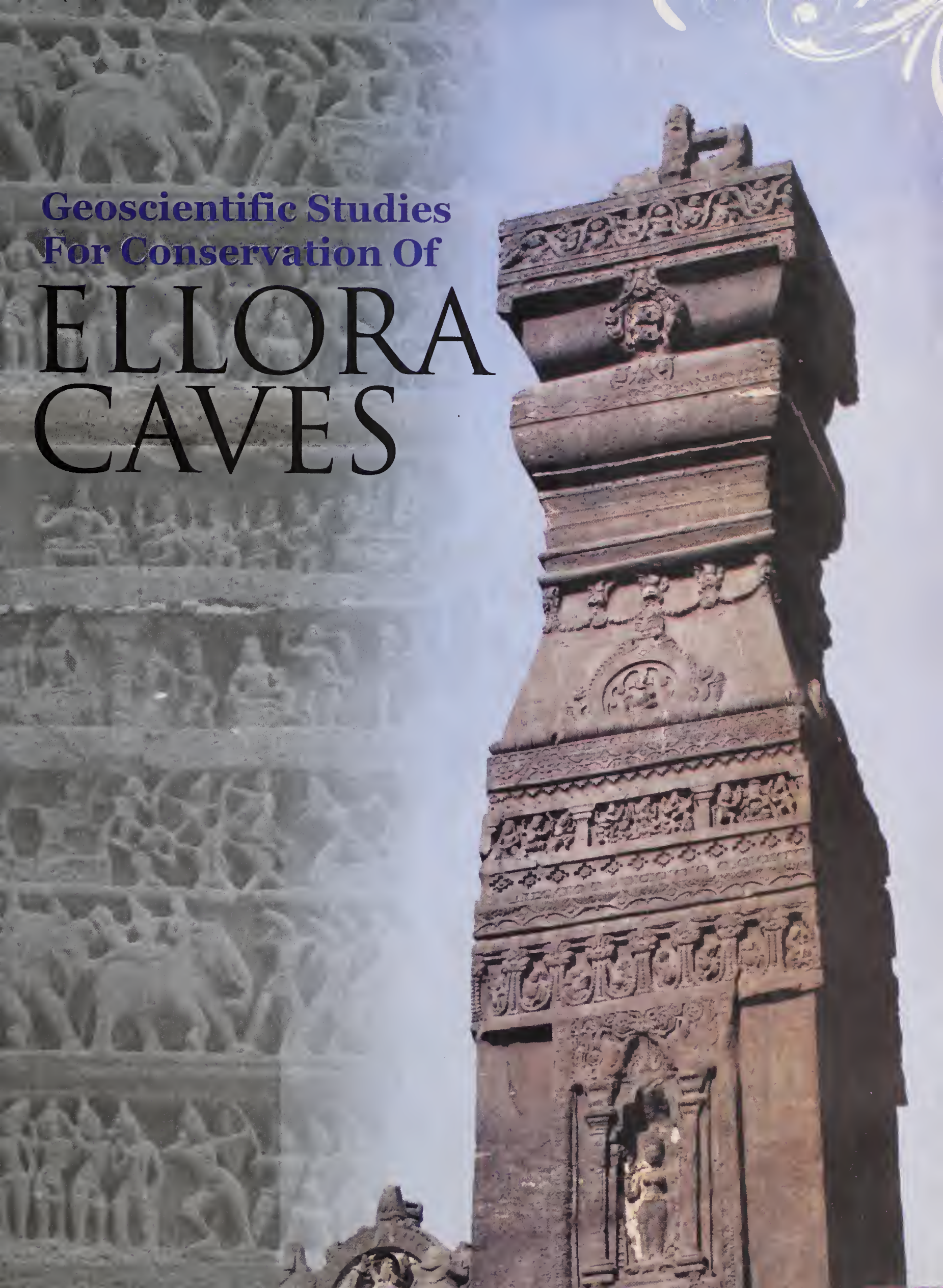
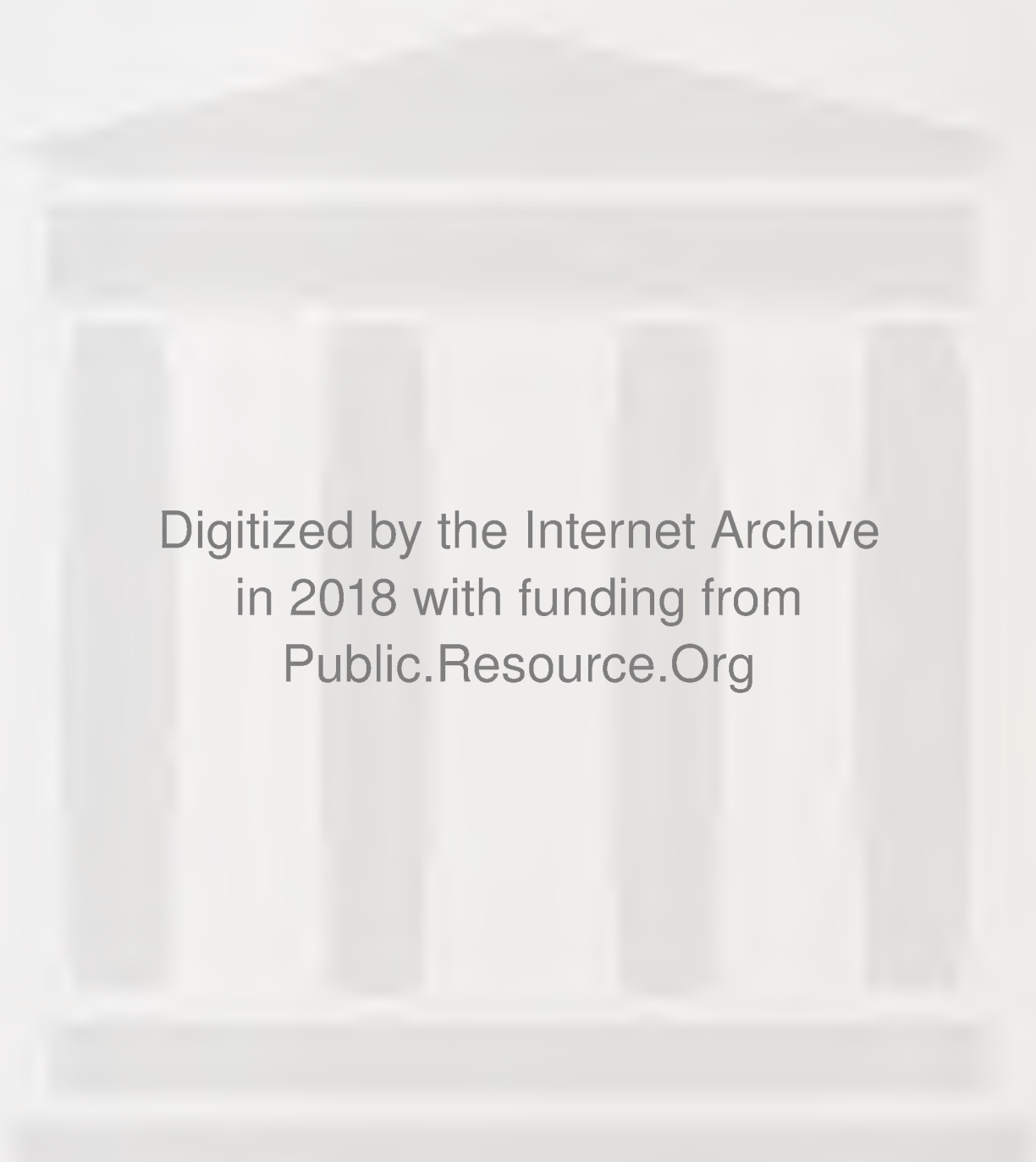


Geoscientific Studies
For Conservation Of

ELLORA CAVES



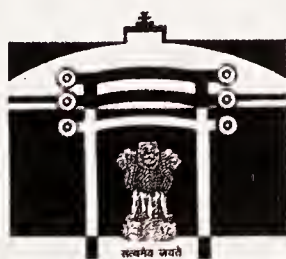


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GEOSCIENTIFIC STUDIES FOR THE CONSERVATION OF ELLORA CAVES

Edited by
Manohar Sinha
Dy. Director General (Retd.)
Geological Survey of India



प्रत्नकीर्तिमपावृणु

Published by
The Director General
Archaeological Survey of India
Janpath, New Delhi

2011

First Edition, 2011
(1000 copies)

©
2011

ARCHAEOLOGICAL SURVEY OF INDIA
GOVERNMENT OF INDIA

Price : Rs. 1000.00

PRINTED AT THE PUBLIC PRINTING (DELHI) SERVICE
C-80, OKHLA INDUSTRIAL AREA, PHASE-I, NEW DELHI-110020 PH. 26811431

FOREWORD

Ellora is a magnificent set of rock cut caves and also known as cave temples represented by elaborate carvings of gods and goddesses and are the devotional products of three religious faiths viz Buddhism, Hinduism and Jainism. The ensemble of 34 caves cut out in the Deccan basalt are lying in a north-south direction for a distance of about 2 km situated at 30 km from the city of Aurangabad in Maharashtra. Caves 1 to 12 display Buddhism, 13 to 29 are of Brahminical origin and 30 to 34 exhibit Jainism. Cave 16, which is also known as the 'Kailash' is a marvel of cave excavations and displays rock cut architecture at its best. Approximately 0.3 million cubic feet of rock has been excavated to carve out this exquisite cave temple. The ancient rock cut temples are our national heritage and since it is a world heritage monument it is also the pride possession of the mankind but the site is beset with many geological and environment problems.

The natural process of weathering and erosion alongwith retreating scarps have caused degradation of slopes and have damaging impact on the sculptures and paintings in the caves and in environs. Biotic interference has deteriorated the caves and their surroundings even further. Unstable slopes and seepages are the two major causes of concern while attempting preservation of these monuments. Thus the Archaeological Survey of India engaged the Geological Survey of India (GSI) in 1998, to carry out Multidisciplinary Geo-scientific studies of the cave site. The GSI studied out geological, geohydrological and environmental conditions of the site.

Various studies like topographic survey, geological mapping and geophysical surveys were undertaken in the area. Some specialized studies like stereo-photographic studies of vulnerable slopes, geotechnical studies within and outside the caves were done. Seismic assessment by micro earthquake studies and environmental impact assessment of the caves and their surroundings were also carried out. Geological and geotechnical studies were handicapped because only non-interfering and non-destructive methods could be used in and around the monuments. Sub-surface information also had to be collected and inferred from methods other than drilling to examine the rocks.

The GSI submitted an excellent report in 2001 on the studies carried out containing various thematic maps, damage assessment of the site from geotechnical perspective and their remedial measures and have also given suggestion for improving the environ of the caves.

The suggested remedial measures include shotcrete with rock bolt at selected places. Construction of new drains and the improvement of the existing caves by providing fresh lining. The potential benefits of shotcrete as surface support have been realized to a progressively increasing extent in the past decade. Shotcrete can be used to clad the rock surface and to fill in the undulations in the rock surface, control water seepage, protect steel components against corrosion and to provide a tough wearing surface to retard progressive weathering. The initial application of shotcrete close to the face stabilizes ground and promotes quality bolting, meshing and lacing.

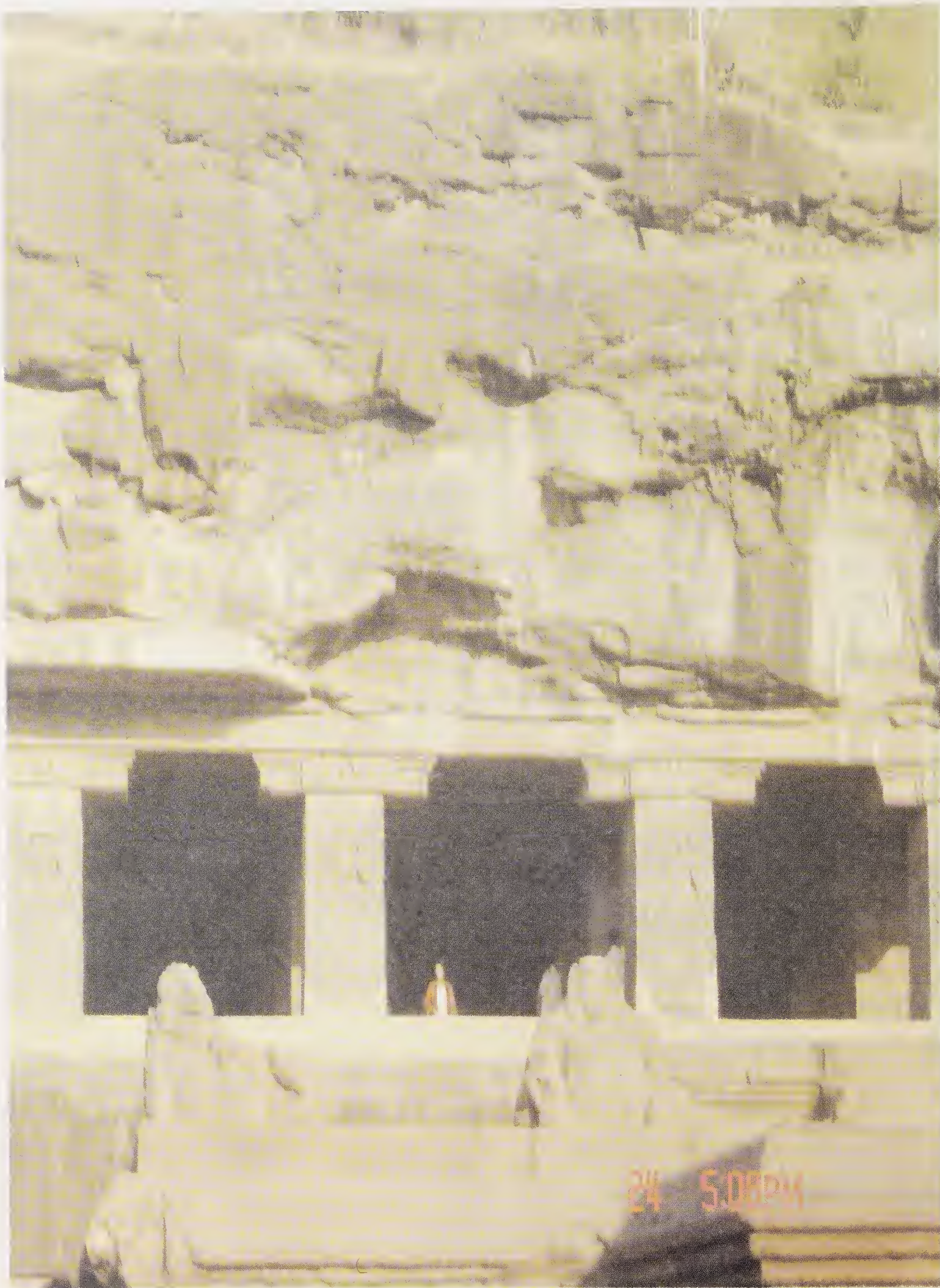
The comprehensive Geoscientific studies for the monuments housed in the rock have been carried out for first time in the country. Similar studies have been carried out for seven sites in the states of Maharashtra and Madhya Pradesh beginning from 1998. Some of the suggestions have already been implemented by the ASI. The protection measures involving the facades and inter-cave areas need more detailing to facilitate the Implementing Agency to design the measures. The protection measures like shotcreting and rock bolting of facades have not yet been implemented since they involve many other aspects on which a holistic approach is to be taken.

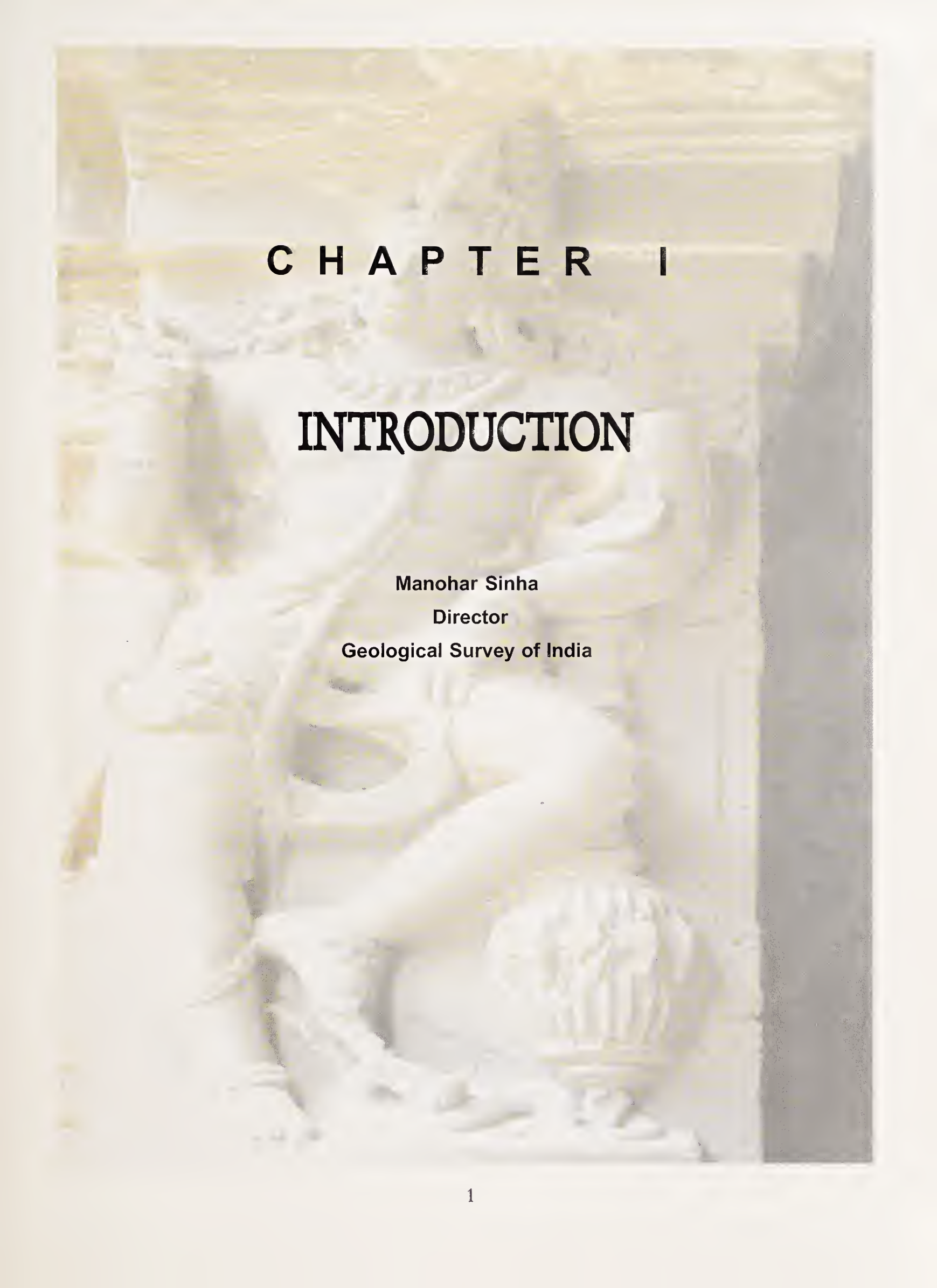
The Archaeological Survey of India is publishing the report containing the accounts of multidisciplinary Geoscientific studies for providing the first hand detail information of the site on which further studies and research can be carried out to evolve the most suitable measures for the sites which should take care of the aesthetic beauties of the site and its integrity. I am sure the publication will provide the archaeologists a document, the reading of which will help them in understanding the intricacies of the rock surface which play an important role in determining the protective measures. The Ajanta report has already been published and this is the second publication in the series of seven publications contemplated. I am confident it will also provide a good reading for all those who have interest in the monuments of the country.

(Gautam Sengupta)
Director General
Archaeological Survey of India

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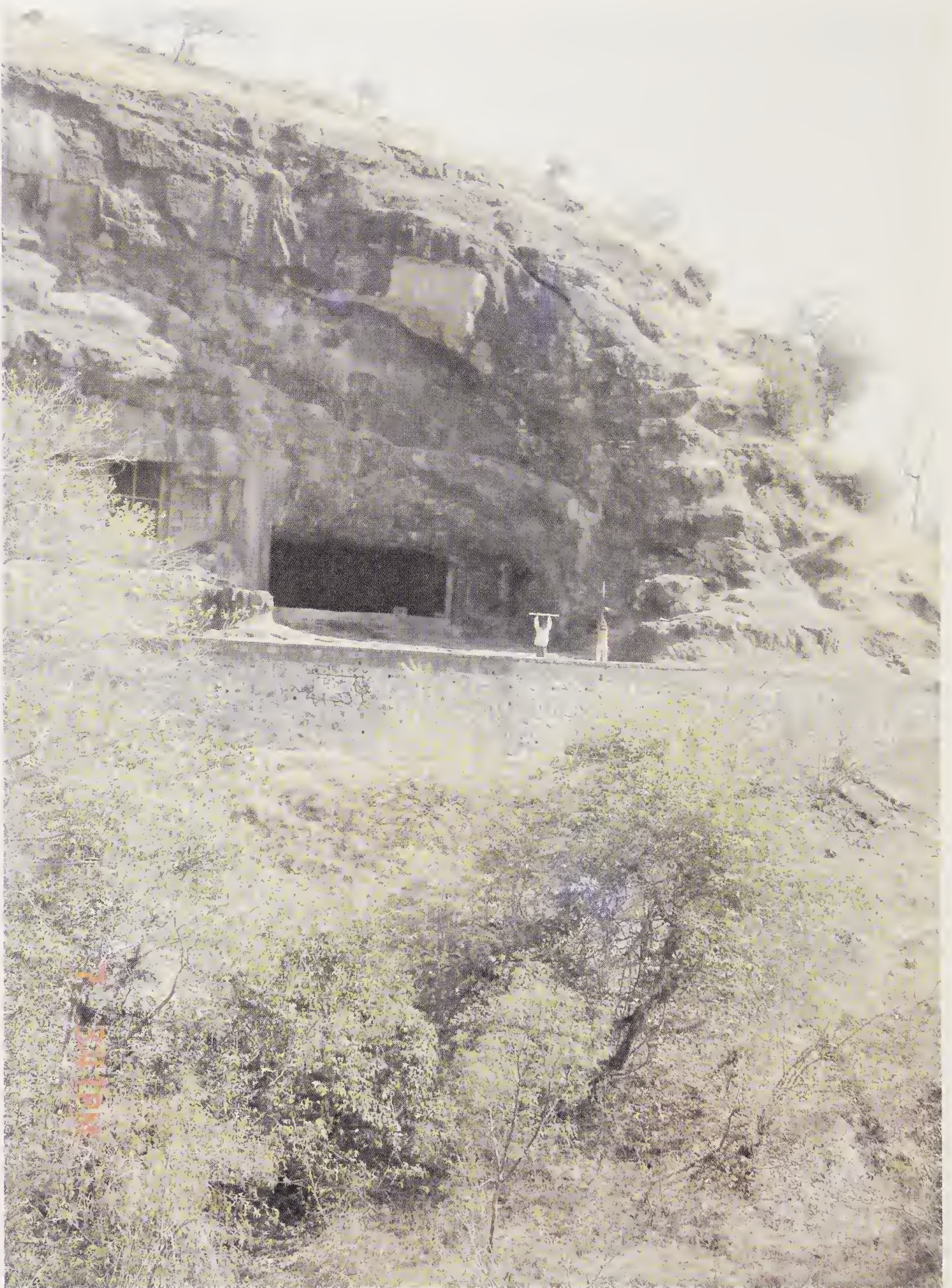




C H A P T E R I

INTRODUCTION

Manohar Sinha
Director
Geological Survey of India



CHAPTER-I

INTRODUCTION

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I. INTRODUCTION

ARCHAEOLOGICAL AND HISTORICAL PERSPECTIVE

Ellora caves represent an unique repository of magnificent rock cut caves belonging to early medieval period of Indian history. This assemblage of 34 caves carved in the Deccan basalt is visible for a distance of about 2 km in north-south direction and is situated at a distance of 30 km from Aurangabad in Maharashtra. It was declared World Heritage site in 1983 by the UNESCO.

Ellora caves display three major religious traditions of the Indian sub-continent, Buddhism, Jainism and Brahmanism. The caves were carved over a period of five to six centuries and they exhibit technological development in architectural style. The need for monsoon retreats for itinerant monks was the guiding factor for making cave retreats. The earliest of such caves are found in the Nagarjuni and Barabar hills in Bihar and were made in the 3rd century B.C. Thereafter cave architecture flourished in the Deccan under the patronage of rich Buddhist and Jain merchant guilds. The last phase of Buddhist cave architecture in Western India is seen at Ellora. The architecture and sculpture here shows some continuity with the earlier cave temples of Ajanta, Bagh and Kanheri. Here the shrines are larger and the sculptures are lavish in scale and prolific in detail.

This part of Deccan had been inhabited in the late middle stone age as evidenced from the

occurrence of stone tools of Jasper, attributable to an industry of the pre-microlithic facies and subsequently in the microlithic and chalcolithic periods. The history of the Ellora caves begins within historical times, a little over five hundred years after the birth of Christ¹. However, it is very intriguing that the *Satavahanas*, whose coins have been picked up from the vicinity of the caves and during whose times the trade-route was in use, have not left any trace of their activity on this hill. The historical antiquity of the caves together with their authorship beyond doubt still remain to be established. However, putting together all evidences it is now generally believed among historians that by the close of the sixth century the excavation of the Buddhist caves began at Ellora. The chronology of the caves can be put in three periods, pre-Rashtrakuta, Rashtrakuta and post Rashtrakuta phase². The excavations of Buddhist group of caves 1 to 11, caves 15, 16 and 22 to 28 in the Brahmanical group and caves 30 to 32 in the Jain group belong to the Rashtrakuta period. The excavations of Buddhist group of caves 1 to 11 and other Brahmanical excavations excepting cave 21 may be assigned to Chalukyas, the predecessor of the Rashtrakutas. However, the cave 21, Ramesvara, has an image of Lakulisa on the architrave of the main entrance to the temple and is purely Saiva in character. It may be ascribed to the Kalachuris of Mahishmati, who were avowed Pasupatas, styling themselves Parma-mahesevara. The historical findings indicate that they wielded

1. K.V. Soundara Rajan and R. Sengupta, 'Flake and blade tool industries from Ellora', *Proceedings, 48th Session, Indian Science Congress (Calcutta, 1961)*, P. 449
2. R. Sengupta, *Repairs to Ellora caves, Bulletin of the Archaeological Survey of India 1961*, pp. 46-67.

power over a territory from Nasik to a part of the ancient Asmaka country including Bhogavardhana. Bhogavardhana has been identified with modern Bhokardan, Aurangabad district, about 50 miles to the east of Ellora. The Kalachuri association of this cave is also identified by the find of a silver coin of Krishnaraja¹ just in front of the caves.

The excavation of the caves has to be sequenced with ruling dynasties, the activities probably were initiated by the Kalachuris, followed by the Chalukyas in an atmosphere of tolerance. The successors of the Chalukyas, the Rashtrakutas maintained the harmony and tolerance amongst the followers of three religions Buddhist, Brahmins and Jains during the ninth century and promoted competition with each other in representing their respective religions art. It was this atmosphere of peaceful co-existence that made it possible for different religions communities to forget their rivalry and Ellora witnessed them working together, borrowing motives and conceptions from each other. The Jains were active at Ellora even during the rule of Yadavas in the thirteenth century.

The caves of Ellora were never lost in oblivion because of their close proximity to the ancient trade route and the accounts left by the eminent persons from time to time. The earliest reference of Ellora caves is found in the accounts of Arab geographer Al-Mas'ūdī². Subsequently, Firish³ mentioned the caves in connection with the romantic capture of princess Deval-devī by the party of imperial soldiers in pursue of king

Karan Rāi of Gujrat. Later, Thevenot (in 1633-67)⁴, Niccolao Manucci (1653 to 1708)⁵ Charles Warre Malet (in 1799)⁶ and Seely (in 1824)⁷ wrote on these caves.

After the decline of the Rashtrakutas, attention moved away from the caves. The Yadavas who were initially feudatories of the western chalukyas, succeeded the Rashtrakutas in the 12th - 13th centuries A.D. The Yadava king Bhillama V made Devagiri his capital and excavated the first stage of the rock fort. They were saivas and may have patronized the Kailasa temple at Ellora.

The Holkars of Indore controlled the region of Ellora including the caves. They used to auction the caves for the right of worship and collection of some sort of entrance fee. The village together with the caves was subsequently exchanged with some land near Hyderabad, after which Nizam acquired the ownership of the caves.

Architectural Development at Ellora:

There are 14 to 15 Brahminical caves between the Buddhist and Jaina caves. In their earlier caves, the Brahmins copied to a certain extent the arrangements of those belonging to the Buddhists, though gradually emancipating themselves from their influence till the series culminated in Kailasa, the largest and the most magnificent rock-cut temple in India. The dice game between Siva and Parvati is peculiar to Ellora, while other motifs appear at Elephanta and elsewhere. Raven Ki Khai sculpture is reminiscent of Tantric practices owing to the recurrence of images of Kali. Lakulisa Siva was an important Kalachuri deity.

1. R. Sengupta in *Journal Numismatic Society India*; XXII (1960), Pp.193-95

2. C. Barbier de Meynard, Macoudi—*Les Prairies d'Or*, tome quatrieme (Paris, 1914), p. 95.

3. John Briggs, *History of the Rise of the Mahomedan Power in India* (London, 1829), I, p. 367.

4. *The Travels of Monsieur de Thevenot into the Levant* (London, 1687), pt. iii, Pp. 74-76.

5. Niccolao Manucci, *Storia do Mogar*, tr. William Irvine, I (London, 1907). Pp. 152-53.

6. *Asiatic Reaserches*, VI (1799), Pp. 389-423

7. John B. Seely, *The wonders of Ellora* (London, 1824).

Kailasa is similar in design to the Virupaksha temple at Pattadakal. At Kailasa the work commenced not from the face of the rock, but from three mighty trenches cut in the solid rock, two of them at right angles to the front of the rock and the third connecting their inner ends leaving nearly an isolated mass in the middle to be carved both on the outside and interior into a great monolithic shrine with numerous adjuncts. It measures 164 feet from east to west and 109 feet across, rising to a height of 96 feet to the top of the dome. Interiors were plastered over and painted, perhaps the latest layer was during the Ahilyabai period of temple restoration. Sculpture was a form of political iconography during the reign of the Rashtrakutas, as Krishna I, sponsor of the Kailasa temple, had his coronation inside the temple.

The Rashtrakutas also sponsored building many of the Jaina caves, which were developed during their reign, as the Rashtrakuta Amogavarsha I was a Jain. Jaina caves are separated by a distance of about 200 yards from the Dumar Lena (cave 29) and occupy the northern spur of the hill called Charandari. These are cave 30-34 and they date from 8th to 13th century. Cave 30 known as *Chhotakailasa* is a curious example of the imitation of the works of one sect by the votaries of another on a much smaller scale.

An attempt was made to imitate the cave 16 known as Kailasa but it ended in an incomplete excavation. However, it may also be concluded on the basis of similarity in design with Kailasa that these two temples cannot be far distant in date.

GENERAL INTRODUCTION

Situated at the foot of a N-S trending hill range showing a relief of about 120 m, with

extensive plains of the Shivna river to the west, are the cave temples of Ellora representing elaborate carvings of gods and goddesses of three major religious faiths prevalent in India.

The natural processes of weathering aided by agents like wind, water, temperature variations, biotic interference, along with scarp retreat have had a serious and deleterious impact on the sculptures and paintings in the caves and its environs. These have affected macro as well as microstructures in the rocks, to bring about a gradual deterioration in the rockmass quality. Grade II weathering signifying slightly weathered rock, is prevalent in most of the exposures outside the caves, while the rock inside the caves are generally fresh and unweathered. Patches of moderately weathered basalt are seen in the toe portion of some caves and in inter cave areas. The thickness of the weathered zone is around 1- 2 m. Accentuated weathering is seen along basaltic flows unit contacts, which has led to the destruction of many pillars. Unstable slopes and seepage are the two major causes of concern that are to be mitigated while applying conservation methods.

Slope stability problems at Ellora are confined to the cave portals and the adjacent inter cave slopes that bound them. The slopes immediately behind the caves are flatter / gentler and stable. Deep semi-circular scarps, 20 to 37 m in height have been formed by water action of cascading nals near caves 5, 17, 24 and 29. The outer portions of caves 1 to 9 have perished, creating an overhanging block from which certain parts have been dislodged. Overhangs created by excavation of caves have also become vulnerable at a few places, especially in cave 16. Other than this, certain blocks have collapsed due to separation along flow unit contacts. Stability problems, which are in general restricted to the outer 1-4 m in most caves are due



to overhangs created by differential weathering and also due to jointed and fractured blocks. The cave interiors are relatively stable. The presence of sets of joints, three vertical and the fourth a steeply dipping set of relief joints along with the fracture zone and cooling cracks, have accentuated weathering and rendered the cave facades and certain slope segments weak. Wherever this fracture zone has intersected the cave openings, the outer portion of the caves has collapsed as seen in caves 1- 4, 13 and 14. The relief joints with progressive under-cutting of toe have played a major role in the retreat of the slope face by about 5m.

The process of valley formation and widening has been active and the scarp face has been retreating thereby rendering the slopes unstable. The outer portions of a few caves are destroyed. Interior of the caves are relatively stable while the facades and verandahs show varying degrees of instability.

Seepage of water in the caves is restricted to the outer 2 -3m portion of the caves. Surface run-off flowing down the slope permeates down the cracks causing seepage. Some water seepage is because of surface water roll back due to surface tension.

MEMORANDUM OF UNDERSTANDING

The Geological Survey of India undertook a programme of geoscientific studies at the request of the Archaeological Survey of India, comprising topographic surveys and geological mapping of 0.52 sq. km. area, geophysical surveys, geotechnical studies within and outside the caves; terrestrial stereo-photographic studies of vulnerable slopes, seismic assessment by micro-earthquake studies and environmental impact assessment studies of the caves and their surroundings.

A memorandum of understanding to this effect was signed between the Geological Survey of India

and the Archaeological Survey of India for carrying out multidisciplinary geological, geotechnical and environmental appraisal of Ajanta and Ellora caves and for suggesting mitigatory measures for the problems faced in conservation of the caves. The memorandum provides for the following scope of work:

- Geomorphological studies based on photogeological and remote sensing methods of 100 sq. km. area and preparation of maps on 1: 25,000 or 1: 50,000 scale.
- Topographic survey involving an area of 0.52 sq. km. on 1: 500 scale with 1m contour interval.
- Detailed lithological and structural mapping of the area on 1:500 scale including tracing of micro and macro structures that have possible bearing on seepage and slope stability.
- Geophysical survey (SP and resistivity) of the area for detection and delineation of seepage zones.
- Geotechnical studies on stability of caves and assessment of rock falls from the roof of the caves, as well as steep slopes that bound the caves and approach roads.
- Cave mapping of all the caves.
- Geoenvironmental appraisal including surface water, ground water, land use/ land cover and studies of noise levels and air quality (based on 12 hourly samples on the spot).
- Evaluation of Seismic status of the area by detailed structural analysis and collection and interpretation of data on seismotectonic evaluation and estimation of earthquake hazards by Micro Earthquake studies.



The MOU also includes a provision for extension or enlargement of the project involving advanced and detailed work, based on the result of present study as per mutually accepted terms and conditions, if necessitated.

LOCATION AND ACCESSIBILITY

The Ellora caves are located at a distance of about 30 km from Aurangabad. The area falls in Survey of India sheet no. 46P/4 and bounded by latitude $20^{\circ} 01' 10''$ and $20^{\circ} 02' 00''$ N and longitude $75^{\circ} 10' 40''$ and $75^{\circ} 10' 55''$ E. The city of Aurangabad is well connected by air, rail and road route.

OBJECTIVES OF THE STUDY

The main objectives of the studies are:

- To understand the nature, source and extent of water seepage in the caves and to detect and delineate the seepage conduits and channels in the rock mass above and adjacent to the caves. Suggest remedial measures to arrest or minimise such seepage and protect the caves, its paintings and sculptures from further degradation.
- To assess the existing stability of the caves in terms of various geotechnical parameters and the likely impact of the artificial vibrations and earthquakes around the cave area and suggest mitigatory measures.
- To understand the effect of various elements of physical environment on the cave monument and suggest suitable remedial measures.
- To generate necessary base-line data on topography, geology, geomorphology, geohydrology, environment and geotechnical stability that will be used for evolving the

monitoring system for the proper maintenance and conservation of the monuments.

- Soil profiling at different locations on the cave area to know their physical and chemical characteristics.

SCOPE OF THE PRESENT STUDY

To achieve the above-mentioned objectives, following multidisciplinary geoscientific studies were carried out:

Regional geomorphological and geological maps for an area of about 100 sq.km. around Ellora caves were prepared by digital image processing and aerial photo interpretation of the remotely sensed data and published maps followed by field checks.

Topographic map of the study area was prepared by theodolite survey, which contains topographic and cultural details. Reduced levels of some important reference points in the area were established by dumpy level with reference to triangulation station outside the area.

Geological map is based on detailed ground observations of geological features including physical properties of the rock assemblage. Different basaltic lava flows were identified on the basis of different primary structures. The secondary structures including tectonically induced ones, degree of weathering etc. were identified and plotted on the map.

Detection and delineation of **seepage zones** is based on integration and correlation of geological (nature of rock mass, degree of weathering, soil zones), geomorphological (drainage and landforms), structural (joints, fractures etc.),

geophysical (resistivity and SP methods) and geotechnical data collected from the caves and their surroundings. Based on these, integrated surface water management has been suggested.

Geotechnical studies include the identification and demarcation of different slopes; identification of active and vulnerable zones of slopes, seepage and rock fall and detailed structural study of the caves area. Geotechnical studies inside the caves were conducted to identify and demarcate the seepage zones and hazard potential cracks. Evaluation of Seismic status with the help of historical records and MEQ studies was carried out. Based on these studies suitable remedial measures, including shotcreting, reinforced shotcreting and rockbolting, stabilising the slopes have been suggested.

Geoenvironmental studies include the generation/collection of base line data on temperature and relative humidity both inside and outside, direction and velocity of wind, rainfall, ambient noise, ambient air quality, water quality, soil, flora & fauna, visual impacts, etc, its impact assessment in terms of degradation of the caves' environs and sculptures/paintings and to suggest the remedial measures to conserve the cave monument for posterity.

ACKNOWLEDGEMENTS

The editor is highly indebted to Shri Gautam Sengupta, Director General, Archaeological Survey of India for providing the opportunity for publication of this project report which is the fulfillment of the dream of the entire study team of the project. The editor and the authors do not find appropriate words to express their sincere gratitude to Dr (Miss) Arundhati Banerji, Superintending Archaeologist (Publication), A.S.I., New Delhi for her continuous support and help during the process of finalisation of the project report in the form of present publication. They are also very much thankful to Shri P. K. Trivedi, Director (Publication), A.S.I. New Delhi for offering valuable suggestions during the finalisation of the text and plates of the publication, their scrutiny and the administrative help but for which the publication might not have reached the present status. The study team alongwith the editor are thankful to the entire officials of Publication Division, A.S.I. New Delhi for providing various logistic and administrative help in furtherance of the publication. The editor alongwith authors can not forget to accord their gratitude to the entire members of Public Printing (Delhi) Service, New Delhi for their sincere help in the publication.

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30	Shri M. A. Bagde	JTA (W/S)	Central Region	Geophysical studies	January 99 to September 99

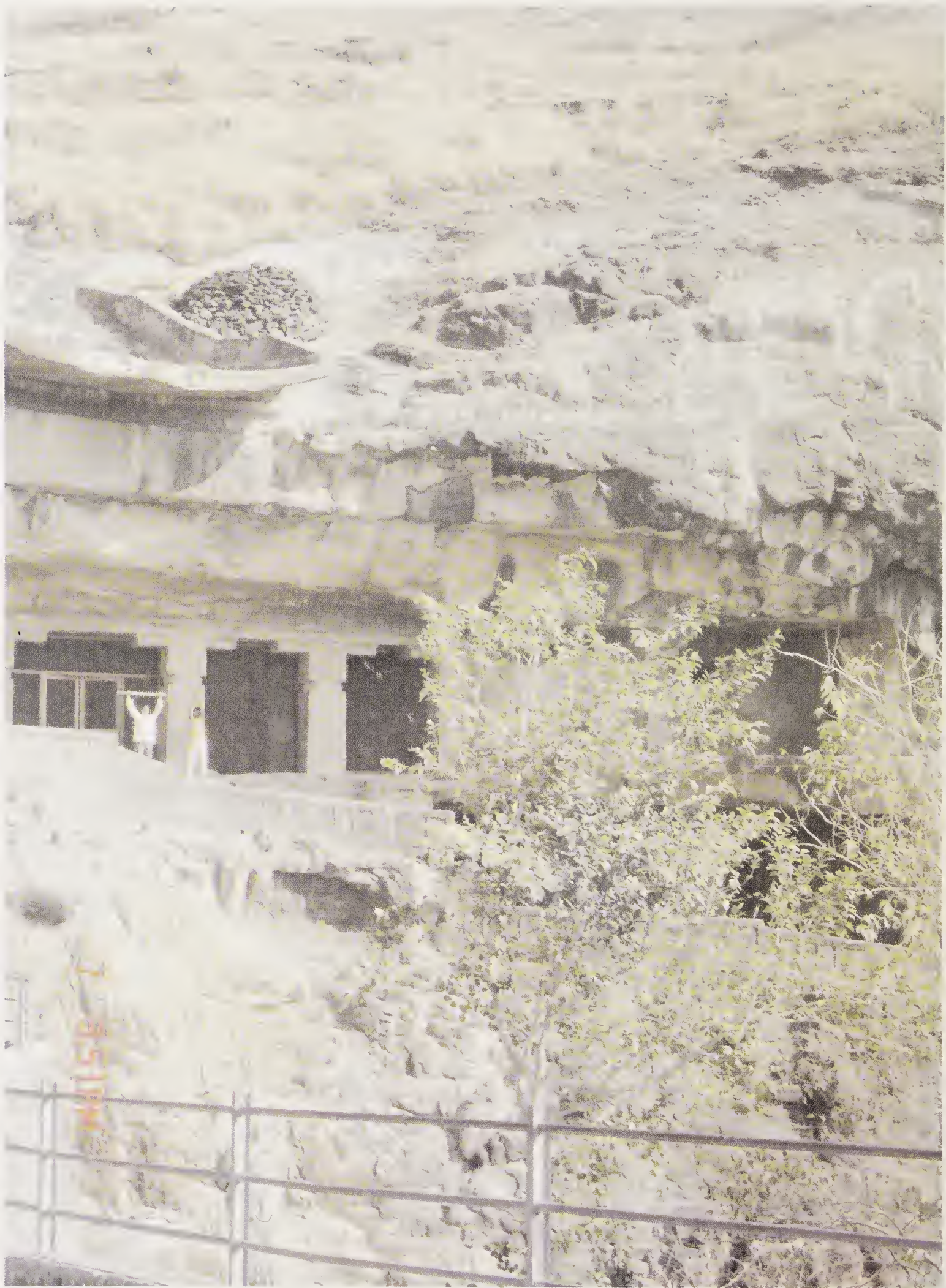


CHAPTER II

**REGIONAL GEOMORPHOLOGY
AND GEOLOGY**

DIGITAL IMAGE PROCESSING
By
S.G. KRISHNA and R.K. SRIVASTAVA,
Geologists (Sr.)

GEOMORPHIC ANALYSIS AND REGIONAL GEOLOGY
By
S. SEKAR, Geologist (Jr)
and
H. Y. BHAI, Geologist (Sr)



CHAPTER-II

REGIONAL GEOMORPHOLOGY AND GEOLOGY

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II. REGIONAL GEOMORPHOLOGY AND GEOLOGY

REGIONAL GEOMORPHOLOGY

G eomorphological analysis of an area of about 100 sq. km. bounded by latitudes 20° 00' to 20° 00' 30" N and longitudes 75° 09' to 75° 15' E in parts of Survey of India Toposheet No. 46 P/4 was carried out on 1:50,000 scale. These studies are based on aerial photo studies and digital image processing with limited field checks.

The area under study forms the eastern valley margin of Shivna sub-basin of Godavari Main Basin and is marked by steeply rising N-S trending plateau popularly known as *Maismal Plateau* in the east and Shivna plains in the west. The southeastern part of the *Maismal Plateau* is dissected and forms the northern valley margin of Purna sub-basin of Godavari Main Basin.

DIGITAL IMAGE PROCESSING

DATABASE: Apart from the toposheet, following data was utilized in the study:

- IRS 1D digital satellite data details:

SENSOR/BANDS	PATH/ROW	RESOLUTION	ACQUISITION DATE
1. LISS-III (4-band data)	P-96: R-58	23.5 m	17.1.99
2. PAN (Band 1 data)	P-96: R-58 Quad. C	5.8 m	9.4.98

- Details of Aerial photographs (1:50,000 scale):

PHOTO DETAILS	ELLORA AREA
Task no./ year of photography.	818-A/ 1975
Run no./ Photo no.	100/ 2-11,102/2-11

METHODOLOGY

Acquired IRS, LISS-III data was loaded from the CD in to the system/ software and the desired areas were extracted. The extracted digital data of the areas were georeferenced with respect to the toposheet.

Similarly, the PAN data was also extracted and registered and then merged with two bands (B2 and B3) of LISS-III. This operation has resulted in achieving better resolution, i.e. 12 m for the FCC.

The digital data was subjected to various enhancement and filtering techniques and was studied in different bands/ band combinations, using both *MULTISCOPE* and *ERDAS IMAGINE* software. Then suitable band combinations were selected keeping in view the various themes desired for on screen digitization. Different thematic maps such as landform distribution with drainage and lineament fabric with possible fault locations etc., were prepared

Stereoscopic studies of aerial photographs and visual interpretation of geocoded hard copies were also carried out and overlays were prepared. Points of interest and/or ambiguity were studied in detail and critical locales were subjected to field checks.

FIELD CHECKS

Limited field traverses were taken twice in the area to check the interpreted thematic maps. The traverses were planned to get the maximum ground truth in critical areas and to verify the geomorphic units, lineaments and faults. During the course of field checks, on spot necessary modifications and corrections were made on the printouts and overlays. Subsequently, these were incorporated in the various thematic maps by image processing and map composition softwares like *ERDAS*, *MULTISCOPE*, *Paintshop Pro* and *Surfer*. Detailed description of various themes and inferences drawn are as follows:

LANDFORMS

The landforms of Ellora area as seen in FCC (Plate: II-1) are: a number of plateau surfaces over Deccan Trap flows with a maximum altitude of 800m. and a minimum of 550 m., above msl with a relative relief of 250m on average and conspicuous scarp aligned north-south, facing towards west.

Nine geomorphic units have been identified in the area (Plate:II-2). These are as described below:

Alluvial plains: They appear in shades of light blue with tinges of pinkish or reddish tones and smooth texture having matte pattern in standard FCC. The plains have developed as low lying flat surfaces west of scarp.

Undulating plains: Areas showing light brown tone between the scarp and alluvial plains characterised by rolling topography have been demarcated in this category.

Colluvial Plains: White to cream colored patches in the FCC having sparse vegetation with gullies and rills on gentle slopes of the scarp face and undulating plains are classified under this category.

Scarp Face: This unit can easily be identified by its dark greenish blue tone all along the scarp, having moderate to steep slope towards west.

Plateau Surface Remnants: Areas in cream color with tinges of blue and brown seen to the east of scarp having corroded/serrate margins are identified under this class. Depending upon their altitudes they are termed as PSR 1 (high level surface), PSR 2 (middle level surface) and PSR 3 (low level surface).

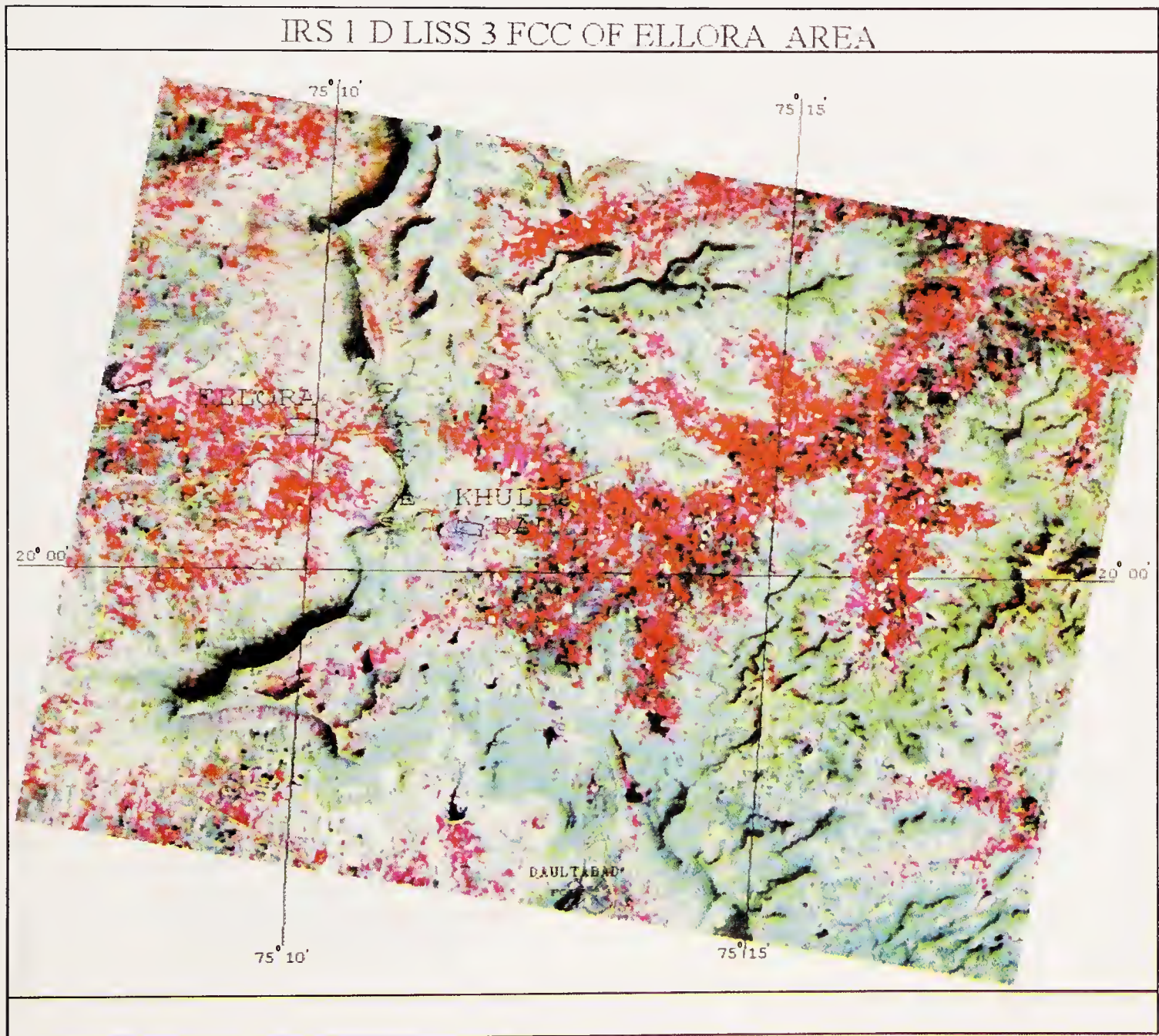
Rugged Slope Zone: This landform shows moderate to high relief and is identified by its cream color with tinges of green along the valley walls. The unit is observed in north and southeastern part of the project area.

Plateau Plains: Plateau plain tracts are recognised by their pinkish red tone and occupy nearly 25% of the area. These are flat surfaces with gentle gradient towards northeast. They occur in the central and eastern parts.

Mesa: Isolated patches of light brown tone with high relief landforms present on the plateau surface remnants are identified as mesas.

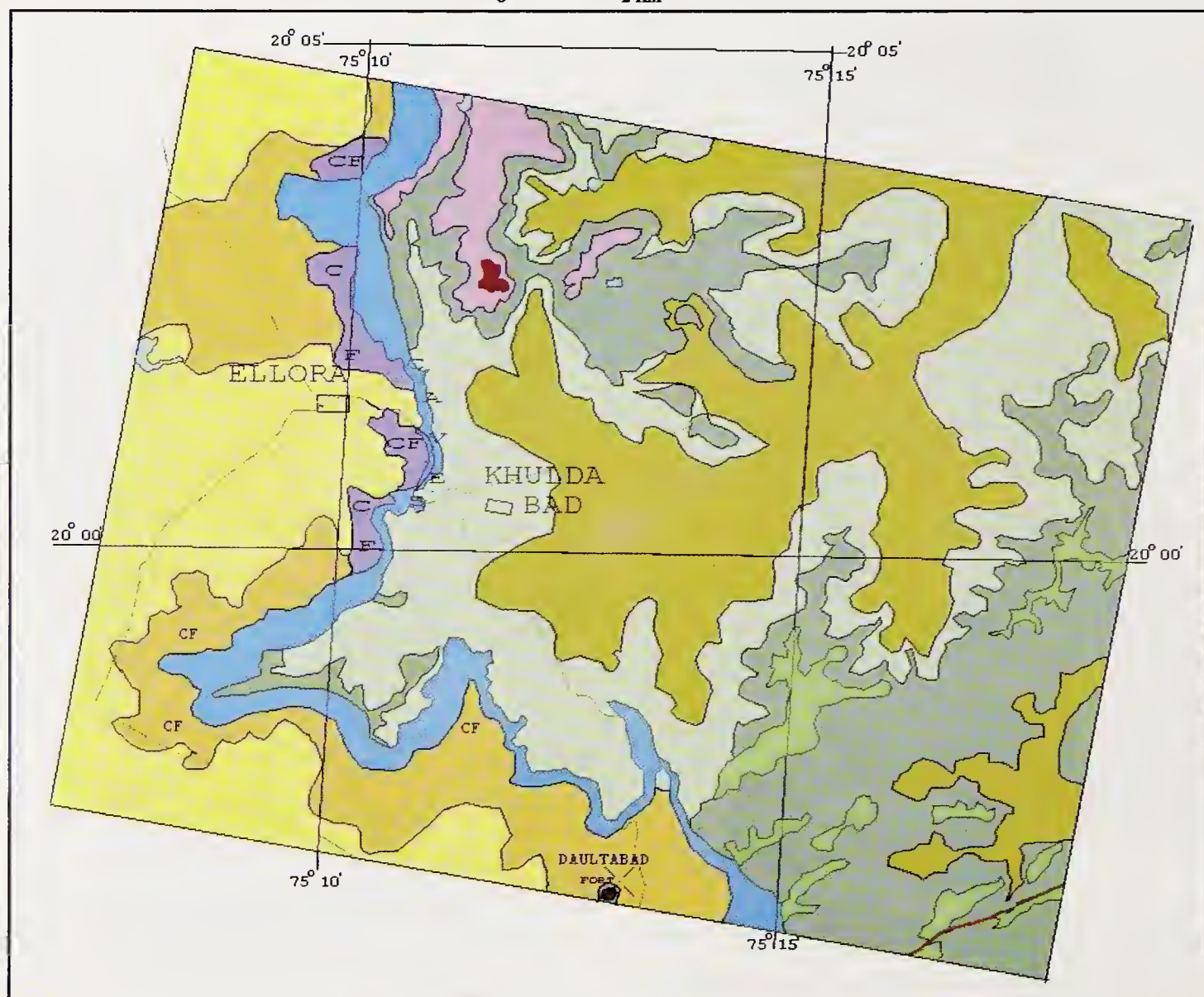
Linear Bodies: These are long, linear, narrow detached bodies with moderate relief with greenish-blue tinge. These bodies are seen in the southeastern corner of the area and possibly represent dykes.

Plate : II-1



GEOMORPHOLOGICAL MAP OF ELLORA AREA AURANGABAD DISTRICT, MAHARASHTRA.

SCALE
0 1 2 KM



INDEX

	ALLUVIAL PLAINS		PLATEAU PLAINS
	UNDULATORY PLAINS		SCARP FACE
	COLLUVIAL FANS		RUGGED SLOPE ZONE
	WATER BODIES		PSR 3
	LINEAR BODY		PSR 2
	MESA		PSR 1
			PLATEAU SURFACE REMNANTS



LINEAMENT FABRIC

Four major sets of lineaments, viz.- NNW-SSE, NW-SE, ENE-WSW, NE-SW directions, (Plate II- 3) are delineated in the area. Intersection of these lineaments is noticed at different locations. They are manifested as prominent scarps, linear ridges, narrow valleys with high angled scarps and rectilinear drainage pattern. Sharp turns, waterfalls and rapids along the stream courses are noticed associated with the lineaments. Occasionally they show silicification / calcification along the trends with concurrent joints and fractures. From the analysis it appears that the NE-SW trending lineaments are the oldest while those trending north-south and east-west, are the youngest.

The caves are located in the north-south trending *Ellora* scarp. This is the most conspicuous and unique linear feature of this area. Badland development with rills and gullies as seen to the north and south of Ellora caves. Presence of waterfalls along streams like Jogeshwari nala, coupled with steepness and straightness of the scarp are suggestive of tectonic disturbance. Minor slips/ displacements are noticed in some of the caves. About 2 km east of the scarp another parallel lineament seen along the gap between 886m and 888m above msl peaks passes through Khuldabad and extends upto Daultabad in the south. Plateau surface around 886 hill slopes towards north while that around 888m hill towards southeast. Development of badland, slips, rapids, ponds, narrowing of the valleys etc are indicative of a possible fault along this lineament. This fault is

intersected by a roughly east-west trending lineament passing through the hills. Alignment of the gaps across spurs/ ridges, extending towards SE from 846m peak, indicates presence of another possible fault/fracture trending in NE-SW direction.

GEOMORPHIC ANALYSIS

Based on quantitative estimates of terrain factors such as altitude, relief, average slope etc, two broad genetic classes have been distinguished i.e.

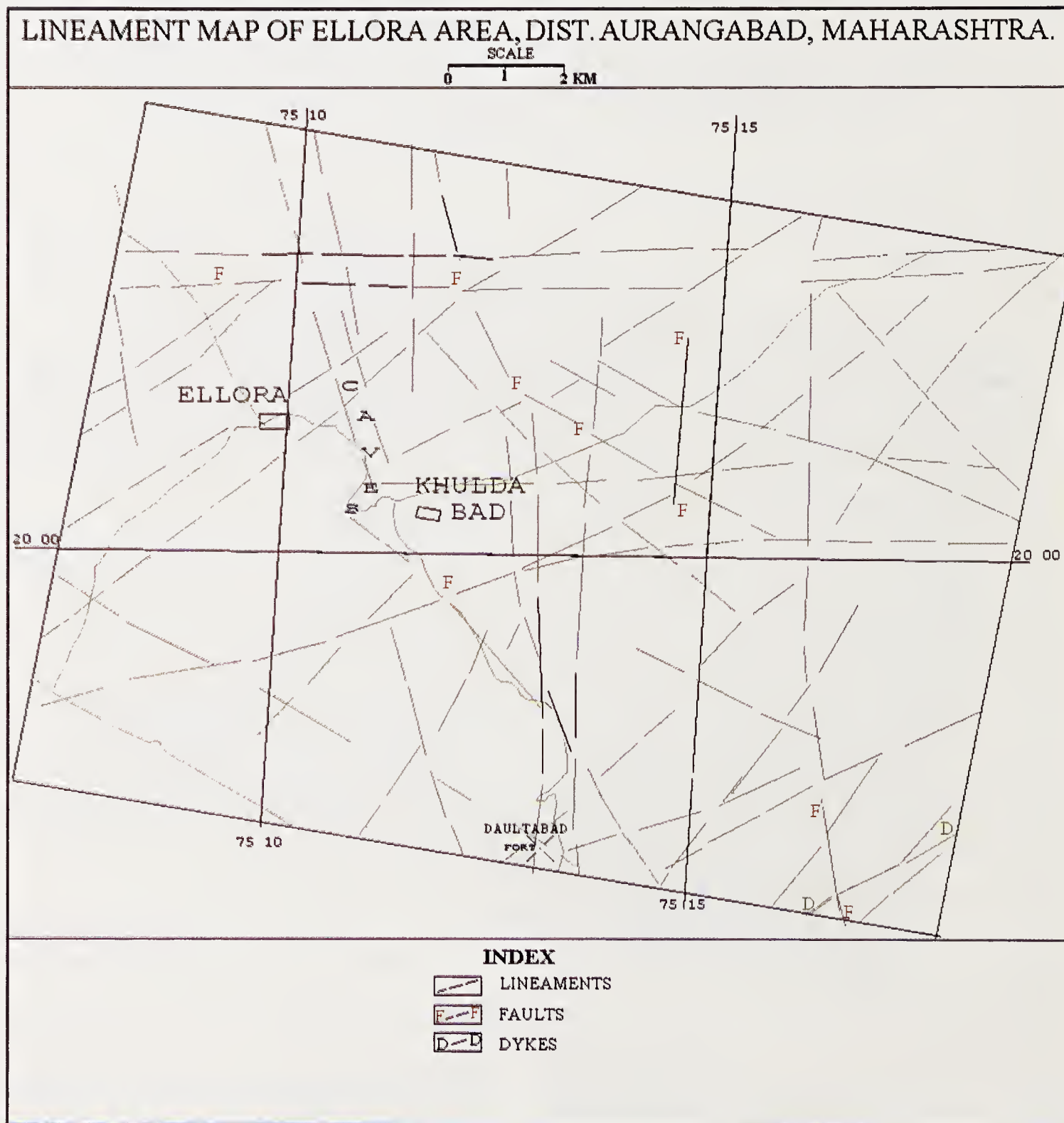
- Forms of extrusive origin (significantly modified by denudational processes) comprising ridges, valleys, plateaus, scarps and planation surfaces and
- Forms of fluvial origin comprising undifferentiated flood plains including infilled valley deposits.

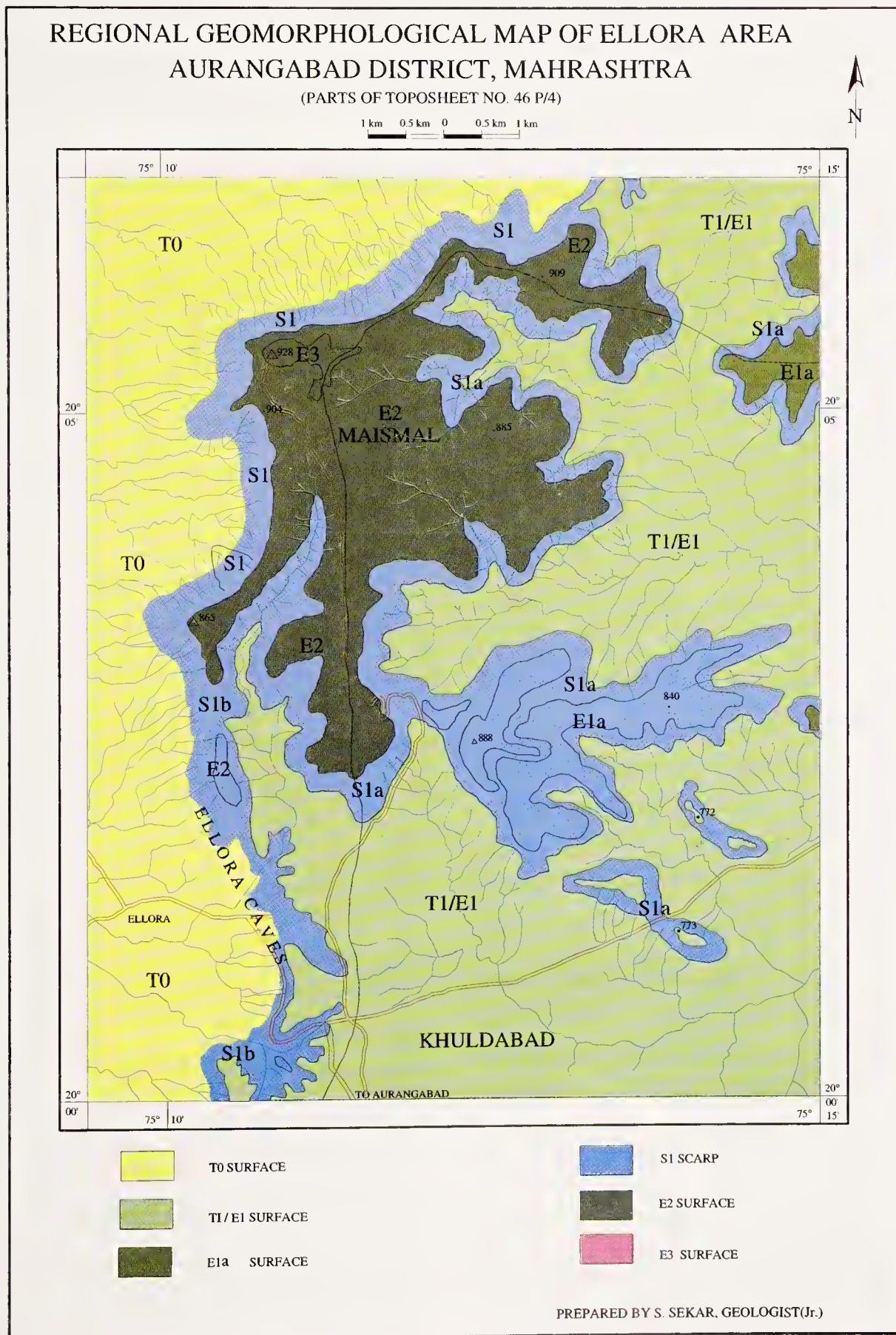
The different morphometric elements identified in the area (Plate II-4) are:

1. Relief Pattern: a) Terrace/ Planation Surface, b) Scarps
2. Slope Pattern
3. Drainage Pattern

RELIEF PATTERN

The area is occupied by Deccan Trap basalt, which shows persistent flatness with gentle to very gentle gradient towards south and southeast. The area has undergone three stages of peneplanation. The morphometric elements seen in the area are discussed below (Plate II-4):





PROCESS	MORPHOMETRIC ELEMENT	NATURE	MORPHOSTRATIGRAPHY
Fluvial	T ₀ Surface	Depositional/ Erosional	Upto 10m thick deposits of undifferentiated alluvium and colluvium and Deccan Trap basalt
Fluvial Structural	S ₁ Scarp	Erosional	Deccan Trap basalt
Extensively modified by denudational processes	T ₁ /E ₁ Surface	Erosional Depositional	Deccan Trap basalt, undifferentiated alluvial deposits and infilled valley deposits of Purna sub-basin.
Extensively modified by denudational processes	E ₂ Surface	Erosional	Deccan Trap basalt
Extensively modified by denudational process	E ₃ Planation Surface with Remnant Hills	Erosional	Deccan Trap basalt

TERRACES / PLANATION SURFACES

Four surfaces are recognised in the area, which are described below (Plate II-4):

E₃ Planation Surface: This is the oldest surface present in the area, 880m above m.s.l and above. This surface is seen as summits of small isolated hills with flat tops/or with peaks rising upto 920m above msl within the E₂ surface.

E₂ Erosional Surface: This is the most widely developed surface in the area and occurs between 780m to 840m above m.s.l in the north and northwestern part of the area. This surface slopes southeasterly and is popularly known as *Maismal Plateau*.

E₁ Erosional Surface/ T₁ Terrace: This surface is most extensively developed in the eastern part of the study area forming Khuldabad plains at 720-740m above msl. An intermediate subsurface E1a

between E₂ and E₁ surface at 840 m above msl, sloping southeasterly is locally developed. Thin zone of infilled valley deposits and undifferentiated flood plain deposits parallel to the course of easterly flowing Purna River and its tributaries occupy this plain. Inter fluvial areas are occupied mostly by Deccan Trap basalt.

T₀ Terraces: This surface is seen below 600m above msl in the western part of the area, forming the undifferentiated flood plain deposits of Shivna river and its tributaries.

SCARPS

A prominent scarp S₁ of about 160m between 640m and 800m above m.s.l is seen along the north- south trending, eastern valley margin of Shivna river. The slopes in the scarps are predominantly steep with intermittent moderate slopes and at place precipitous, thereby giving rise



to small flats and overhangs respectively. This scarp is further sub-divided into two i.e.

- Upper scarp S1a and
- Lower Scarp S1b separated by a well-developed E_1 surface in the southern part of the area.

Upper Scarp S1a: This upper scarp is developed between 840m and 720- 740m above msl and separates E_1 surface from E_2 surface. The upper scarp truncates between 720-740m above msl giving rise to extensively developed E_1 surface in the eastern part of the area.

Lower Scarp S1b: This scarp is well developed in the southern part of the study area and it separates E_1/T_1 surface from T_0 surface. This scarp is developed between 700-640m above msl. The slopes in the scarp are steep with intermittent moderate to precipitous giving rise to minor flats and overhangs. All the caves at Ellora are housed in this scarp.

SLOPE PATTERN

Slope pattern of the area can be broadly divided into:

- Gentle to moderate slopes over plateaus and terraces
- Steep to very steep and precipitous slopes forming scarps and overhangs.

DRAINAGE PATTERN

A well marked N-S trending water divide between Shivna and Purna sub basins passes through E_1 , E_2 and E_3 surfaces which is almost parallel to S1a Scarp. This water divide takes an easterly swing near the Maismal Plateau viewpoint. The two tributaries i.e. Shivna and Purna of Godavari river are the fourth order consequent streams

having perennial flow. Secondary drainage pattern in the area is mostly subdendritic and sub-parallel. First order and second order streams exhibit trellis pattern. Streams originating from E_3 and at places from E_2 surfaces show radial drainage pattern. East of the water divide, the streams show higher sinuosity, sharp turns and meanders constituting rectangular and subparallel patterns, most of them feeding Phulmasta nala, a tributary of Purna river.

CONCLUSIONS

The area shows three stages of peneplanation. The raised level of E_1/T_1 surface, which forms the present flood plain of Purna river, marks the latest uplift. The 60m rise of E_1/T_1 surface with respect to T_0 is the direct manifestation of neotectonism. This is further corroborated by the presence of numerous relief joints parallel to scarp face and raised alluvial deposits as seen in front of cave No. 19, 29 and 34 and youthful stages of second and third order streams.

The sub-horizontal plateau landform of Deccan Basalt at Ellora area had been carved into the present day landscape by dynamic fluvio-denudational processes involving denudation, erosion, sheet wash and slope wash.

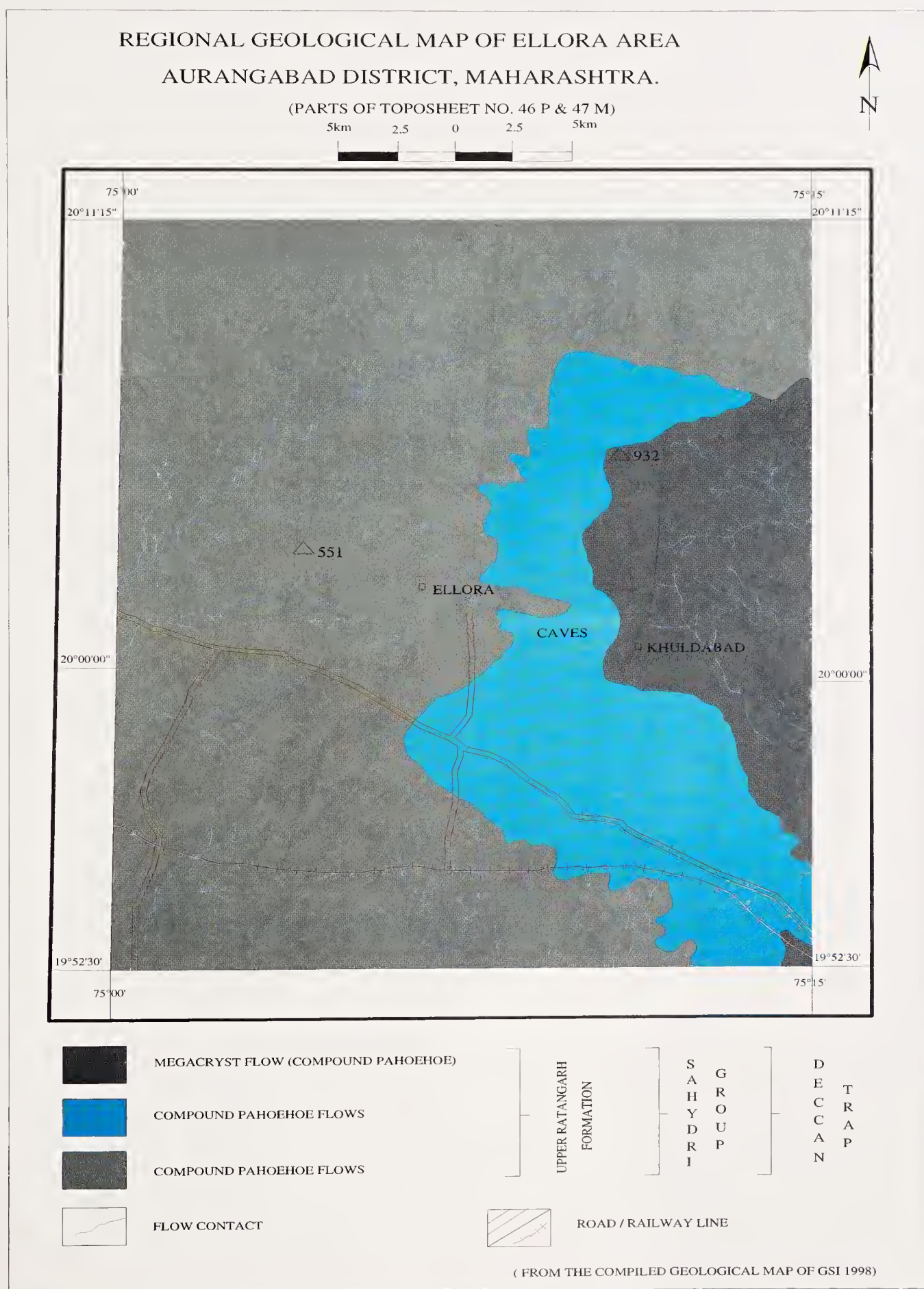
REGIONAL GEOLOGY

The area under study is occupied by a sequence of basaltic flows of Deccan Traps (Plate II-5). The generalized Stratigraphy as per GSI, CR compiled and published Map of 1994 is given below :

The Ellora caves area exposes the Upper Ratangarh Formation comprising 7 flows of which 5 are compound pahoehoe type and two are Aa type flows. The topmost flow is a megacryst flow, which is a regional marker flow in the area, The thickness of individual flow ranges from 15 to 32 m.

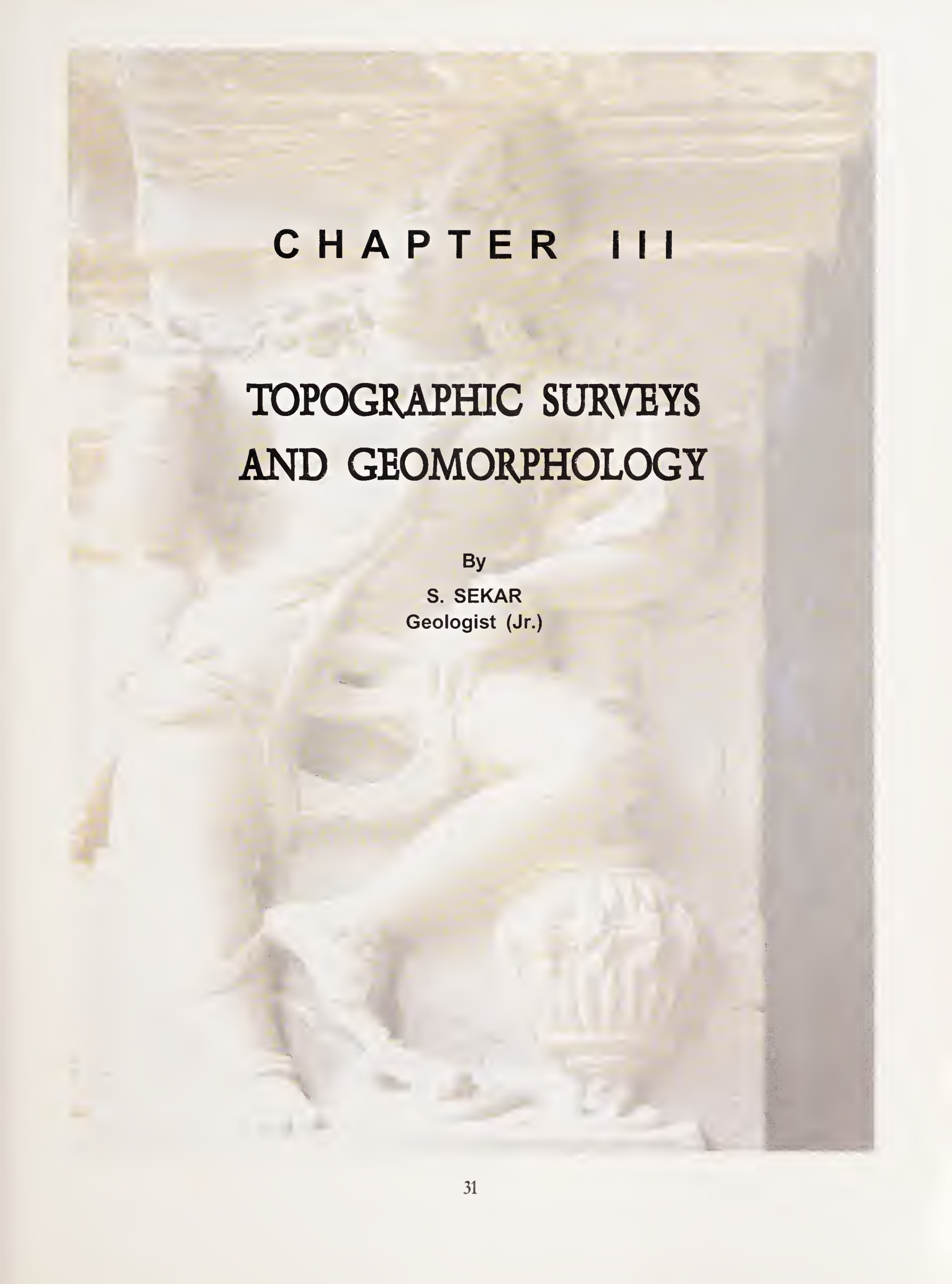


Super group	Age		Group	Formation
D E C C A N	U	L	S	PURANDARGARH FORMATION
	P	O	A	
	P	W	H	DEVIGHAT FORMATION
	E	E	Y	
	R	T	A	INDRAYANI FORMATION
T R A P	O		D	
	C	E	R	UPPER RATANGARH FORMATION
	R	O	I	
	E	C		LOWER RATANGARH FORMATION
	T	E	G	
	A	N	R	
	C	E	O	
	E		U	
	O		P	
	U			
	S			





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C H A P T E R I I I

TOPOGRAPHIC SURVEYS AND GEOMORPHOLOGY

By
S. SEKAR
Geologist (Jr.)



CHAPTER-III

TOPOGRAPHIC SURVEYS AND GEOMORPHOLOGY

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III. TOPOGRAPHIC SURVEYS

Topographic survey covering an area of about 0.52 sq.km. between latitude $20^{\circ} 01' 10''$ and $20^{\circ} 02' 00''$ E and longitude $75^{\circ} 10' 40''$ and $75^{\circ} 10' 55''$ N falling in parts of Survey of India toposheet No. 46 P/4 was carried out on scale 1 : 500 with 1M contour interval, as part of Multidisciplinary Geoscientific Studies of Ellora caves area, under Ajanta-Ellora Project (Plate III -1). The survey work was carried by S/Shri. L. J. Deshpande, STA (S), B. L. Balghare, J.T.A. (S), D.K.Ghugari, J.T.A. (S), S.S.Ghavgave J.T.A. (S) and D.D. Barde S.T.A. (S).

Detailed geological mapping on 1:500 scale was also carried out along with topographic surveys.

METHODOLOGY

The methodology adopted for topographic, geological surveys and cave delineation is divided into four stages and are described below: -

BASE WORK

The base work carried out for topographic survey is as follows: -

- i) Ellora caves area was covered by forming 52 small well-conditioned triangles.
- ii) Baseline was laid between Triangulation stations T0 and T1. The distance between these two stations was measured five times using steel tape and after giving level corrections; its average length was calculated. This average length was taken as base for side calculations.
- iii) The magnetic bearing of line T0 and T1 was observed and recorded using prismatic Compass.
- iv) All included angles of the triangulation stations were measured using micro-optic Theodolite and reading from both faces were recorded. Mean angle was taken for calculation of sides of the triangles and bearing of the line.
- v) The other sides of the triangles were calculated using sine rule.
- vi) The co-ordinates were calculated with respect to triangulation station T1 assuming its latitude and departure as 5000 (Table V - 1).

TABLE - 1

LOCATION OF TRIANGULATION STATIONS IN ELLORA CAVES

LINE		WHOLE	CIRCLE	BEARING	STATION	R.L.	LATITUDE	DEPARTURE
T0	T1	167°	00'	00"	T1	619.485	5000.00	5000.00
T1	T3	146°	29'	50"	T3	642.305	4912.39	5058.65
T3	T13	62°	51'	40"	T13	673.865	4964.77	5160.84
T13	T4	289°	36'	30"	T14	615.910	5002.88	5053.77

T4	T10	58°	48'	20"	T10	684.200	5048.18	5128.56
T10	T12	76°	56'	10"	T12	702.405	5068.01	5214.03
T12	T11	341°	29'	00"	T11	707.695	5157.65	5183.95
T11	T9	302°	46'	50"	T9	688.940	5199.84	5118.35
T9	T8	326°	36'	40"	T8	673.700	5259.84	5078.74
T8	T7	255°	35'	30"	T7	643.540	5234.99	4982.14
T7	T14	288°	23'	20"	T14	615.910	5267.44	4884.41
T14	T0	150°	09'	10"	T0	619.515	5110.20	4974.61
T0	T1	167°	00'	00"	T1	619.485	5000.00	5000.00
T7	T15	3°	57'	00"	T5	642.215	5326.86	4986.95
T14	T15	59°	49'	40"	T15	642.265	5326.98	4986.84
T15	T17	41°	59'	00"	T17	662.890	5365.57	5021.47
T17	T21	356°	17'	40"	T21	675.100	5524.96	5011.03
T21	T25	8°	16'	40"	T25	690.460	5612.62	5023.60
T25	T27	330°	39'	50"	T27	674.620	5687.71	4981.36
T27	T29	321°	19'	00"	T29	665.845	5770.09	4915.16
T29	T33	338°	20'	00"	T33	647.420	5909.47	4859.66
T33	T37	262°	58'	30"	T37	653.385	5903.22	4808.76
T37	T39	334°	16'	30"	T39	658.785	5962.26	4780.18
T39	T40	276°	31'	20"	T40	648.555	5968.80	4722.57
T40	T43	24°	34'	30"	T43	676.975	6068.66	4768.13
T43	T45	348°	07'	10"	T45	692.385	6183.01	4743.95
T45	T49	321°	11'	00"	T49	693.180	6287.41	4659.86
T49	T51	307°	56'	40"	T51	678.445	6363.84	4561.68
T51	T53	312°	08'	20"	T53	676.385	6433.84	4484.17
T53	T52	217°	27'	30"	T52	647.445	6341.39	4413.17
T52	T54	217°	36'	30"	T54	637.140	6267.19	4355.92
T54	T48	116°	40'	00"	T48	629.455	6173.65	4541.80
T48	T44	119°	43'	50"	T44	639.410	6129.71	4618.58

T44	T42	151°	00'	20"	T42	639.240	6029.23	4673.13
T42	T41	176°	40'	30"	T41	630.895	5940.20	4679.30
T41	T38	112°	32'	30"	T38	647.045	5911.61	4747.69
T38	T30	145°	22'	40"	T30	646.200	5851.35	4789.56
T30	T28	166°	50'	30"	T28	639.375	5707.42	4823.52
T28	T26	153°	49'	00"	T26	647.085	5607.55	4872.55
T26	T23	145°	16'	30"	T23	649.500	5547.55	4914.20
T23	T22	158°	43'	40"	T22	648.680	5447.93	4952.68
T22	T24	266°	21'	40"	T24	635.085	5444.49	4898.13
T24	T16	152°	34'	40"	T16	635.175	5401.06	4920.53
T16	T14	195°	05'	20"	T14	615.910	5267.47	4884.41
T14	T15	59°	49'	40"	T15	642.265	5326.98	4986.84

LEVELLING

The reduced levels of the triangulation stations and the established bench marks in the area were determined by physical leveling using "Tilting Levels" and by carrying the recorded level of 605.70 m of the reference pillar (established by Survey of India) in front of Archaeological survey of India office of Ellora caves (toposheet No. 46 P/4 B3 quadrant.)

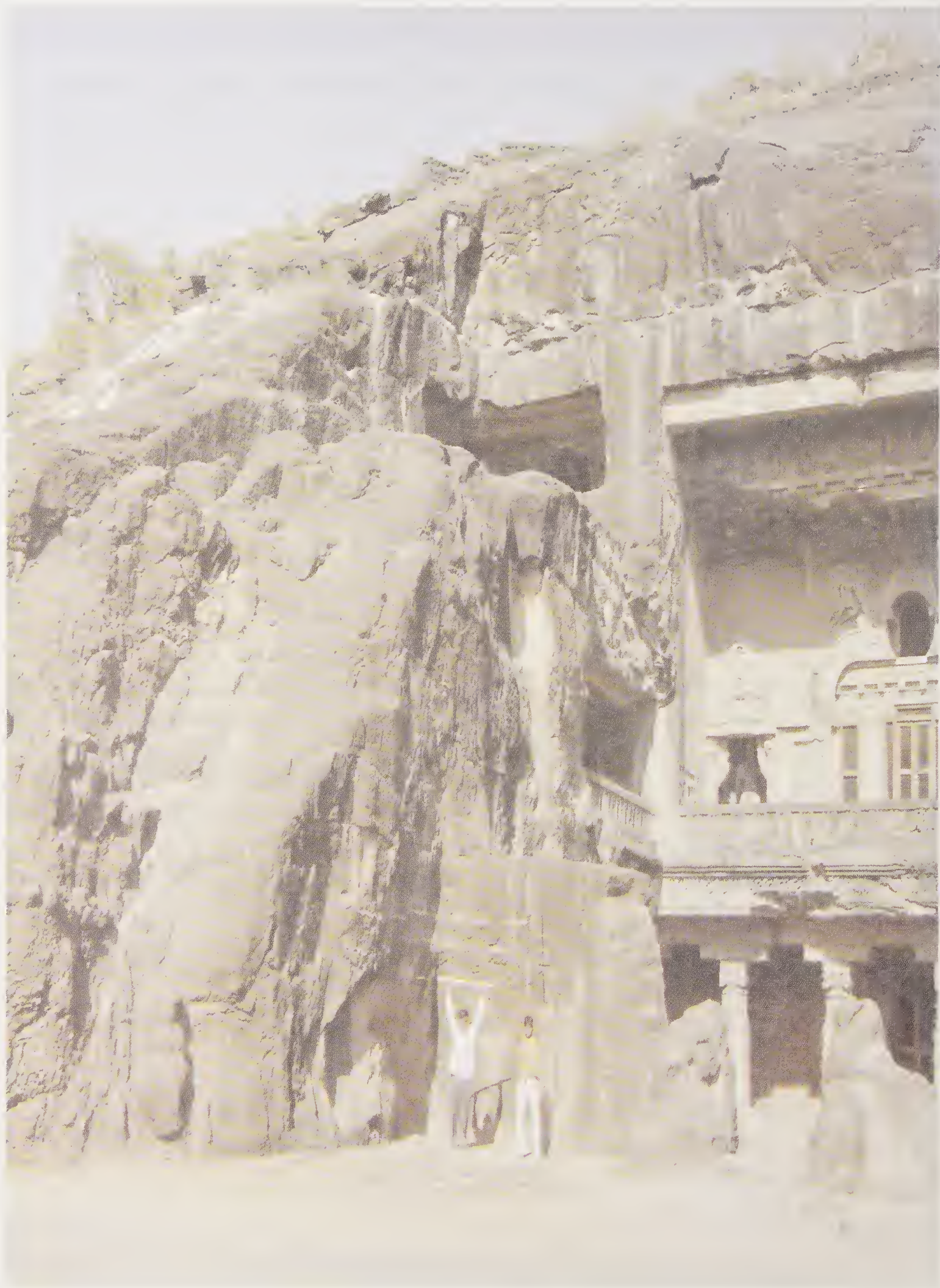
DETAILED FILLING

Topographic and geological surveys.

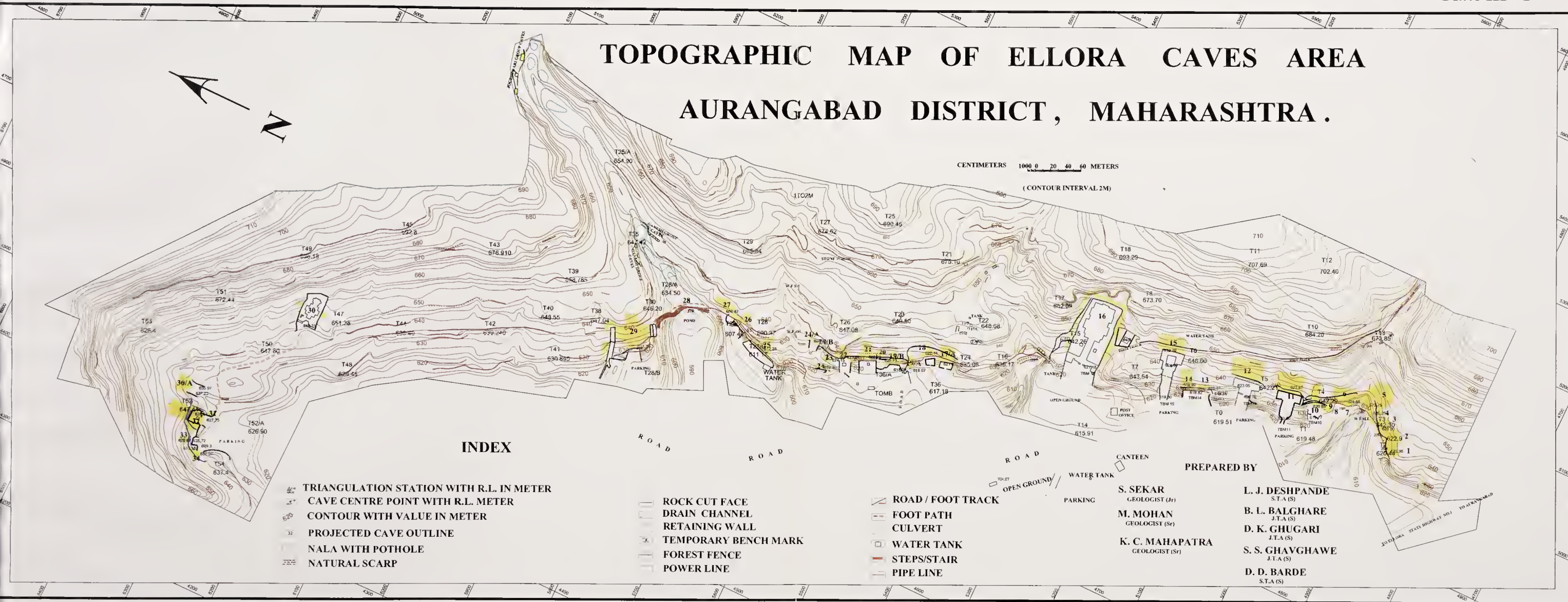
- Radial shots were taken from the triangulation stations established in the area by tachometric method using micro opting theodolite and graduated leveling staff.
- Reduced levels (R.L's) of individual spots were calculated tachometrically with respect to R.L's of triangulation stations.
- These were plotted on 1:500 scale and contours were interpolated at an interval of 1m.
- Care was taken to survey maximum topographic details and civil structures.
- Geological observation points were surveyed with respect to the triangulation stations, plotted on topographic map of 1:500 scale and the contact / data interpolated / inferred between two observation points.

CAVE DELINATION

- Cave centerline was laid using steel tape and micro-optic theodolite for each cave.



TOPOGRAPHIC MAP OF ELLORA CAVES AREA AURANGABAD DISTRICT, MAHARASHTRA .





- ii) The mid point of cave entrance/ opening and the mid point between the walls at the rear/ inside of the cave are joined to form the central line of the cave.
- iii) These lines were connected to the triangulation stations and numbered.

PLOTTING

- i) The area was divided into 100mx100m (plot size of 20cm x 20cm on 1:500 scale) grid, assuming the latitude and departure of T1 triangulation station as 5000 all the triangulation stations were plotted.
- ii) The contours were interpolated at 1m intervals and manipulated according to topographic features.
- iii) Cave dimension were plotted in dashed line and given solid yellow hatch to indicate as projection.
- iv) Different topographic features were plotted using standard symbols and colours as adopted by Survey of India for preparation of toposheet.
- v) The map drawings were later digitized and edited on AutoCAD 14 and AutoCAD 2000 for presentation in magnetic media.
- vi) This map was also reduced to A-4 size and printed with contour interval of 2m.

GEOMORPHIC ANALYSIS OF STUDY AREA AROUND ELLORA CAVES

Geomorphological analysis of an area of about 0.5 Sq. Km around Ellora caves was carried out on 1:500 scale. The different landforms identified, as shown in plate III –2, are discussed below: -

PLANATION SURFACES

Erosional Surface (E1): The Erosional surface (E1)

is seen in the eastern part of the area over caves 6 to 15, 28 and 30 above 690 m. msl. It gently slopes towards south.

Erosional Surface (E1a): Isolated Erosional E1a sub surfaces between 675m and 680m above msl are seen forming prominent table top flats sloping gently towards west above caves 17-21, 25-27 and 29.

Terrace (T0): The frontal of caves between 11 and 29 marks the beginning of T0 terrace at about 620m, above msl. It forms prominent undifferentiated flood plains of Shivna river, sloping towards west. This plain is occupied by undifferentiated flood plain deposits of Shivna river with isolated basaltic inliers.

SCARP

Scarp S1 (b): The lower scarp S1 (b) between 620m above msl to 690m above msl prominently occupy the area surveyed. All the caves are housed in this scarp. The slopes are steep to very steep with intermittent moderate and precipitous thereby giving rise to numerous flats and over hangs.

OTHER LAND FORMS

Entrenched valley: The second and third order nallas cascading down the slopes from E1 surface along S1 (b) scarp form deeply entrenched valleys with valley walls (Banks) of 4 to 10 m height. These are present in nala above cave 5 (N1), between cave 16 and 17 (N2), 24 and 25 (N3) and 27 and 29 (N4). The slopes are very steep to precipitous.

Rapids: Numerous rapids are seen in nallas N1, N2, N3 and N4 having falls ranging from 3 to 37 m.

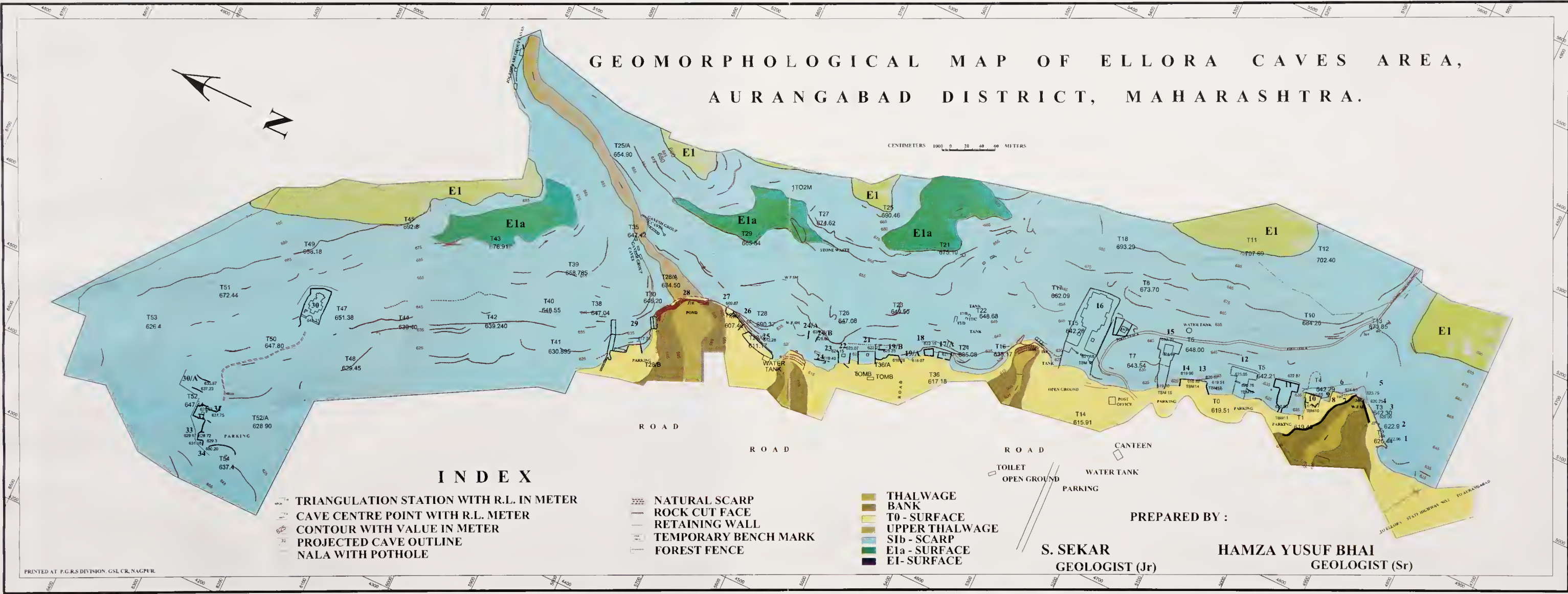
Potholes: Potholes are seen in nallas between cave 27 and 29 forming ponds. The dimensions vary



from $L = 6-10$ m, $W = 2-6$ m and depth 2 to 12 m.

Thalwage: Two prominent Thalwages are seen in nallas N1 and N4. The upper thalwage form prominent areas of erosion and sediment generation and is separated from the lower one with 24m and 37m steep waterfall respectively.

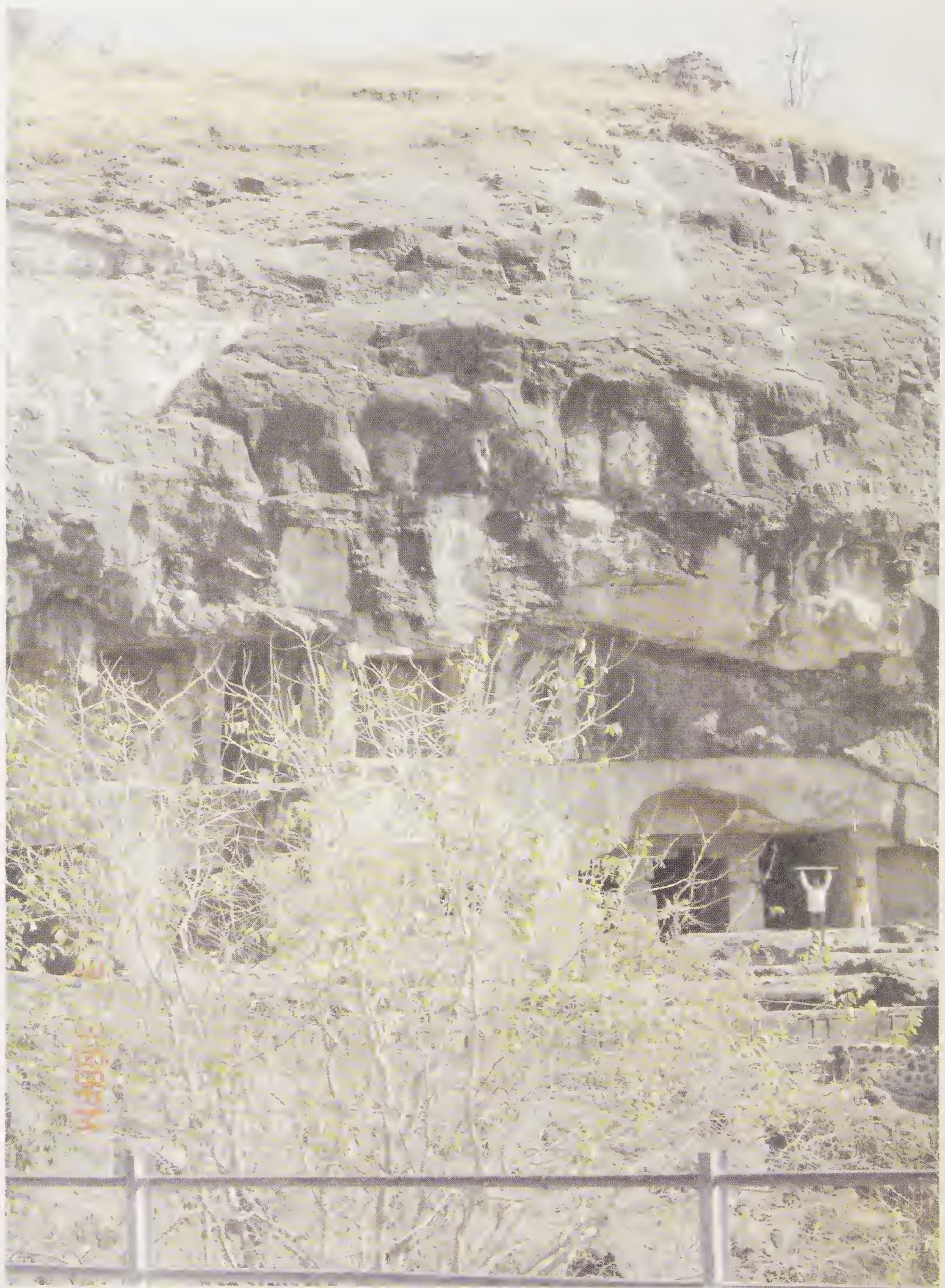
The upper thalwage is occupied mostly by bedrocks, with boulders and pebbles of basalts. The lower thalwage at the head of upper thalwage is occupied by high velocity dumps comprising mostly boulders. In the down stream direction, fining of sediments takes place from cobbles, pebbles to coarse sand. This forms the area of deposition.



CHAPTER IV

**GEOLOGY OF THE
ELLORA CAVES AREA**

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Geologists (Sr.)



CHAPTER-IV

GEOLOGY OF THE ELLORA CAVES AREA

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IV. GEOLOGY OF THE ELLORA CAVES AREA

Geological mapping of an area of about 0.52 Sq. Km bounded by latitude 20° 01' 10" and 20° 02' 00" N and longitude 75° 10' 40" and 75° 10' 55" E, around Ellora caves, falling in parts of Survey of India toposheet No. 46 P/4 was carried out on scale 1:500. The systematic Geological Mapping of Ellora caves area of Kannad Tehsil was carried out on scale 1: 63,360 during F.S. 1973-74 by A.R. Sawarkar. He delineated 21 flows of which the first 18 are Pahoehoe type and the top three are Aa type flows, in a vertical column of 403 m. between 526 and 929 m. above msl.

METHODOLOGY

The geological mapping was carried out by studying the sections from the base of caves to the plateau top and the flows with different units were

delineated and laterally traced in successive sections (Plate IV-1). Ropy surface, vesicular zone and reddened crust at the top and basal pipe vesicles at the bottom help in delineating the unit contact of the compound pahoehoe flow. The presence of impersistent red/green/brown bole bed, varying in thickness from 0.1m to 0.5m help in delineating the inter flow contact between flow No. I and II.

GEOLOGY

The Ellora caves area proper is occupied by two Basaltic flows of the Upper Ratangarh Formation. The flows are of Compound Pahoehoe type with well-developed basal pipe vesicles, pahoehoe toe and ropy surfaces/structures. The Flow Stratigraphy of the area is given below: -

DESCRIPTION OF FLOWS

FLOW STRATIGRAPHY OF THE ELLORA CAVES AREA

Flow	Flow Type	Thick ness (m)	Altitude (m above msl)	Nature of Contact	Megascopic Characters of Flow
II	Compound 'pahoehoe' (15-18) units	50-60 (exp- osed)		Top not exposed in the area	Dark grey, fine to medium grained, moderately to highly porphyritic and moderately to highly weathered.
----	-----	-----	--650-	0.3 to 0.5 m impersistent Red / Green/ Brown Bole	-----
I	Compound 'pahoehoe' (15-18 units)	50-60		Bottom contact not exposed in the area.	Greenish grey to grey, medium grained, moderately to highly porphyritic and moderately to highly weathered.



FLOW NO-I: This is a compound pahoehoe flow, with thickness ranging from 50-60m. It consists of 15-18 units, with individual unit thickness varying from 2 to 6m. A typical pahoehoe unit comprises a top vesicular zone with closely spaced sub rounded vesicles generally filled with silica and zeolites; at places empty also, the middle massive part with widely spaced vesicles or without it and a thin bottom vesicular zone with longitudinal, bifurcated (inverted fork type) basal pipe vesicles and at places pahoehoe toes. The top surface generally shows a thin reddened crust and at many places ropy structures.

The massive part of the units is fine to medium grained and greenish grey to grey in colour. They are moderately to highly porphyritic with clusters of whitish feldspar phenocryst laths ranging in size from a few mm to 1.0 cm. The massive parts in general are moderately to highly weathered.

The bottom contact of this flow is not exposed in the area mapped. The top contact is marked by a very impersistent 0.3 to 0.5m thick red/green/chocolate brown bole between 655-660m above msl as seen in sections above, about 200m NNE of cave no. 16 and north of cave no. 30 A.

All the caves in Ellora area are carved out of the lower units (1-10) of this flow No. I.

FLOW NO-II: This is also a compound pahoehoe flow with an exposed thickness of about 60m. It consists of 15-18 units with similar unit characters of flow no. I. Some of the units pinch and some units are added, particularly in the central and northern part of the area mapped. The top contact of this flow is not exposed in the area mapped.

The thin sections of the basalt samples from the units of flow no. I and II under microscope are fine to medium grained and some are highly

altered. The sections exhibit porphyritic texture with discrete plagioclase phenocrysts and in some sections olivine and clinopyroxene phenocrysts are also seen. The olivine is generally altered to iddingsite. The plagioclase phenocrysts also cluster to form glomeroporphyritic texture and contain inclusions of glass and groundmass materials. The groundmass comprises plagioclase, clinopyroxene, glass, opaques and mesostasis showing intergranular, intersertal to haylophitic texture. The glass/ mesostasis constitutes about 10% to 20% (VE). The glass is altered to palagonite and at some places to chlorophaeite. The opaques occur as rod-like, subhedral to anhedral aggregates and are about 5-10% (VE). In some thin sections vesicles are present, which are irregular in shape, generally empty or at places, inter connected and filled with glass and secondary minerals.

SOILS AND SCREE

The gentler slopes and flat levels of the terraces formed by the different units of the compound pahoehoe flows in the study area around Ellora caves are occupied by soils and scree. The different soils and scree identified in the area are described below:

Black Cotton Soil: This soil is well developed on the E1a and E1 planation surfaces and also along the minor flats above the caves. They comprise mostly of clay with very minor amount of silt and sand. A few nodules of black coloured minerals (ferro magnesium minerals) are also present.

Inceptisols: Incipient development of soil profile is seen at many places along the minor break in slopes on S1 scarp. Development of incipient calcification along with discoloration is also noticed.

GEOLOGICAL MAP OF ELLORA CAVES AREA, AURANGABAD DISTRICT, MAHARASHTRA.

CENTIMETERS 1000 0 20 40 60 METERS

I N D E X

REDDENDED CRUST
ROPY STRUCTURE
PAHOEHOE TOE
COOLING JOINT
RELIEF JOINT
SPHEROIDAL WEATHERING
HIGHLY WEATHERED ZONE

FLOW-II
FLOW-I
FLOW CONTACT
UNIT CONTACT OBSERVED/INFERRED
VESICULAR ZONE
PIPE VESICLES
RED BOLE/GREEN BOLE

TRIANGULATION STATION WITH R.L. IN METER
CAVE CENTRE POINT WITH R.L. METER
CONTOUR WITH VALUE IN METER
PROJECTED CAVE OUTLINE
NALA WITH POTHOLE
NATURAL SCARP

ROCK CUT FACE
DRAIN CHANNEL
RETAINING WALL
TEMPORARY BENCH MARK
FOREST FENCE
POWER LINE

ROAD / FOOT TRACK
FOOT PATH
CULVERT
WATER TANK
STEPS/STAIR
PIPE LINE

MAPPED BY :

S. SEKAR M. MOHAN
GEOLOGIST (Jr) GEOLOGIST (Sr)

K. C. MAHAPATRA
GEOLOGIST (Sr)

DRAWN BY:

VISHVANATH PRASAD
DRAUGHTSMAN



Transported Soils: These are light brown fine sandy to silty soils and occupy the banks of nallas, forming recent flood plain deposits. Thickness varies from a few centimeters to 4 meters.

Scree: In the study area, mostly matrix-supported scree is present along the slopes of S1 scarp. Thickness of scree varies from 20 cms to 1m. Matrix: Clast ratio varies from 60:40 to 90:10. Invariably the matrix content is as high as 70%. Clast supported scree is present only in the higher reaches and are rare in the area of study.

STRUCTURES

The different structures identified in the area can be divided into:

- # Primary structures
- # Secondary structures

PRIMARY STRUCTURES

Cooling Joints: The joints present in the massive part of the units of the area are mostly cooling joints developed by contraction of the lava during cooling. These are straight, curvilinear and irregular also. The polygonal joints, which are crudely developed forming different sizes of blocks of basalt, are also seen in the area. (Plate IV-2) These joints are generally tight and are at places filled with secondary silica.

Ropy Structure: This structure is developed on the top surface of the units and results from dragging and twisting of still-plastic crust of the flow/unit top by movement of fluid lava beneath it along its advancing front, which resembles folds or irregular heaps of cloth (Plate IV-2). Well-developed ropy structures are seen in the nala cuttings. The casts of ropy structure is also seen at the bottom surfaces of the upper units (as seen in the roof of cave no.7)

Incrack-filling/ Squeeze-ups: These are seen in the cave wall cuttings. Lava flowing over the open cracks of the earlier unit surfaces fills up the existing gap and solidifies to form incrack-fillings. These fillings do not have any root and assumes the shape of the pre-existing cracks. Squeeze-ups are formed when the still molten hot lava in the central part of the flow/unit is injected upwards in to the fractures in the solidifying crust and many of these auto-intrusive dykes may reach the surface.

Pahoehoe Toe: The front of a slow moving pahoehoe flow commonly does not advance as a single unit, but rather by protrusions of one small tongue after another called the "toes" (Plate IV-2). These are generally 0.1 to 1m across and extend only 1-2m before they become immobile. The crust of the flow front cracks and allows the emergence of a bulb of red-hot liquid lava, which quickly cools to form toes. The other toes move out on either side of it and still others fill in the spaces between the earlier ones. Commonly the ends of toe cracks open to allow the emergence of another toe and so on.

Pipe Vesicles: They are the tubes projecting upwards into the base of the flow/unit (of compound pahoehoe type) and range from 1-6cm in length and their diameter is usually less than 1 cm (Plate IV-3). The movement of air, trapped beneath the flow/unit and the gas generated by the lava flowing over wet soil and burned vegetation forms the pipe vesicles, after the gas escapes. Some are single rather uniform cylinders and others are branched; particularly common are those in which two or more tubes rising from the base of the flow/unit join upward into a single tube apparently as a result of coalescence of several rising bubbles and are in the form of inverted fork-shape. These are later filled with secondary silica/zeolites to form pipe amygdules.

Plate : IV-2



Crudely developed columnar joints in the section above cave 29.



Ropy structure, in the foot track above cave 29.



Pahoehoe toe, in the nalla section of cave 16

Plate : IV-3



Basal part of unit with pipe vesicles in the road section above cave 10



Massive part of unit showing spheroidal weathering above cave 17a



Gapping relief joint, in front of cave 1 2

Vugs/Cavities: The escaping entrapped gases within the lava of flow/unit leaves behind empty spaces to form Vugs/Cavities. These are generally filled with secondary silica, zeolites and calcite to form Geodes.

SECONDARY STRUCTURES

Exfoliation: This is a weathering process commonly seen in rocks that is cut by sets of joints, i.e. separation during weathering of successive shells from the rock, like “Skins” of onion (Plate IV- 3). The outer most shell tends to be flattish, whereas inner most ones are spheroidal as corners become more and more rounded, hence it is also known as Spheroidal weathering. The joints are avenues of slow movement of water solutions that attack the rock causing chemical weathering. Although the outer surface of exposed rock dries rapidly after wetting, the moisture that penetrates between mineral grains and into crevices remain long enough to cause some decomposition of feldspars to form clay. This process accompanied by increased volume of the weathered rock, probably sets up small forces that causes shell to separate from the main body of the rock.

Joints: Though most of the joints present in the area are cooling joints, some are of diastrophic nature also. The different sets of joints present in area are:

N-S: These joints show a swing of 10° to 15° on either side and are sub-vertical. They are generally tight or filled with silica, linear to curvilinear and do not extend for more than 2-4m. They are confined to single units, rarely cutting across them.

E-W These joints also show a swing of 10° to 20° on either side and are sub-vertical. The joints are commonly tight, linear to curvilinear and do not extend more than 2-4m laterally.

NW-SE: These are tight, linear to curvilinear joints with sub-vertical dips

Basal Joints: These are the horizontal sheet jointing confined to the massive part of the units with rolling dip of 1° - 2° .

Relief Joint: They trend $N10^{\circ}$ to $20^{\circ}E$ – $S10^{\circ}$ to $20^{\circ}W$, with dips varying from 42° to 52° towards W/WSW. These planes/joints are developed due to distressing of the rock mass and are parallel to the scarp slope and are present in all the cave frontals (Plate IV-3). These relief joints with progressive under cutting of toe have played a major role in the retreat of the slope face by progressive collapsing to about 5m.

PETROCHEMISTRY

Petrochemical studies of basalt of the flow No. I, exposed in the Ellora caves area has been carried out on the basis of analyses of fresh samples from the massive part of a few units of flow No. I, in the sections above the caves. The analytical results of major oxides and minor elements are given in table IV – 1, trace elements table IV – 2, the normative composition in table IV – 3 and the different geochemical indices and ratios in table-IV - 4.

The normative composition of the lava flow/units depicts their overall quartz normative tholeiitic nature. All the plots of AFM diagram fall in the tholeiitic field and above 50% FeO (Total FeO), field, indicating initial iron enrichment followed by depletion of MgO, which is typical of tholeiitic magmas. The relation between SiO_2 and total alkali indicates the marginally alkaline nature with their silica content being comparatively lower indicating over saturation and probable transitory nature towards the alkaline field from the tholeiitic field. The plots of MI Vs FI fall in the middle stage of

fractionation with only one sample falling in late stage field, which indicates the more evolved nature of the lava flow units.

It can be concluded that the quartz normative

tholeiitic flow units are more to highly evolved in nature with initial iron enrichment, followed by depletion of MgO. Some units of the flow though tholeiitic, show a marginally higher alkaline nature.

Table IV-1

WHOLE ROCK ANALYTICAL RESULTS OF BASALTS FROM ELLORA CAVES AREA

Sample No,	SS/E/ 1	SS/E/ 2	SS/E/ 3	SS/E/ 4	SS/E/ 5	SS/E/ 8	SS/E/ 9	SS/E/ 10	SS/E/ 11	SS/E/ 12	SS/E/ 13
Flow No.	I	I	I	I	I	I	I	I	I	I	
Major Oxides	VALUES IN%										
SiO ₂	46.05	48.84	47.16	48.08	47.56	44.35	46.93	47.04	47.68	48.12	55.08
Al ₂ O ₃	15.55	14.06	13.19	12.42	12.05	12.20	13.34	12.42	12.45	13.75	12.18
FeO	3.22	5.07	5.38	7.34	Traces	7.02	7.08	6.66	6.12	6.64	Traces
Fe ₂ O ₃	8.23	6.53	7.74	5.92	15.56	7.46	6.02	7.84	8.65	6.48	10.61
TiO ₂	2.12	1.03	1.64	2.55	2.82	3.03	2.81	2.80	2.36	2.12	0.41
CaO	11.60	9.52	11.08	11.71	11.03	11.61	10.81	10.83	9.68	10.04	8.58
MgO	5.11	6.07	5.51	5.63	5.03	5.44	5.20	4.82	4.85	4.98	3.13
K ₂ O	0.86	0.24	1.02	0.32	0.96	0.46	0.78	0.98	1.17	0.86	1.02
Na ₂ O	3.23	3.31	3.64	3.51	3.52	3.48	3.68	3.84	3.71	3.57	3.45
MnO	0.18	0.18	0.17	0.15	0.15	0.15	0.15	0.15	0.14	0.14	0.09
P ₂ O ₅	0.30	0.32	0.38	0.41	0.43	0.43	0.46	0.44	0.43	0.41	0.27
-H ₂ O	1.12	2.35	0.71	0.51	0.15	1.94	0.79	0.67	0.51	0.76	1.12
+H ₂ O	2.23	2.46	2.14	1.42	0.72	2.41	1.85	1.46	1.80	1.90	4.03
CO ₂	Traces	Traces	Traces	Traces	Traces	Traces	Traces	Traces	Traces	Traces	Traces
Minor elements	VALUES IN PPM										
Cu	150	175	200	200	175	225	225	225	175	225	75
Pb	10	10	20	10	20	10	10	20	20	10	30
Zn	100	100	100	100	100	100	100	100	100	100	100
Ni	50	60	50	40	50	30	40	30	40	40	75
Co	30	30	20	20	40	20	30	30	20	20	40
Cd	<10	<10	<10	<10	<10	<10	<10	<10	<10	<10	<10
Ag	1	<1	<1	<1	1	1	1	<1	<1	1	1

Table IV-2

**TRACE ELEMENT ANALYTICAL RESULTS OF BASALTS
FROM ELLORA CAVES AREA**

Trace Elements											
As	<1	<1	<1	<1	<1	2	<1	<1	2	2	<1
Sn	<10	<10	10	<10	<10	<10	<10	<10	<10	<10	<10
Nb	<10	<10	<10	<10	<10	<10	<10	<10	<10	<10	<10
Ta	<10	<10	<10	<10	<10	<10	<10	<10	<10	<10	<10
W	10	<10	<10	<10	<10	10	<10	<10	10	<10	<10
Mo	<10	<10	<10	<10	<10	<10	<10	<10	<10	<10	<10
Zr	100	90	110	100	110	130	140	120	120	120	130
Sr	210	160	160	160	150	170	190	150	160	180	420
Rb	30	10	30	20	20	10	10	10	30	20	30
Cr	120	200	220	190	90	110	100	110	110	110	190
Ba	210	160	270	210	400	320	360	330	360	330	380
Y	<10	<10	10	<10	<10	<10	<10	<10	<10	<10	<10
Th	<10	<10	<10	<10	<10	<10	<10	<10	<10	<10	<10
Ce	<10	<10	<10	<10	10	10	10	<10	10	<10	<10
La	<10	<10	<10	<10	<10	<10	<10	<10	<10	<10	<10
Bi	<10	20	10	20	10	20	<10	<10	10	10	20

Table IV-3

CIPW WEIGHT NORM OF BASALT SAMPLES FROM ELLORA CAVES AREA

Sample No,	SS/E/ 1	SS/E/ 2	SS/E/ 3	SS/E/ 4	SS/E/ 5	SS/E/ 8	SS/E/ 9	SS/E/ 10	SS/E/ 11	SS/E/ 12	SS/E/ 13
Flow No.	I	I	I	I	I	I	I	I	I	I	I
Qtz.	—	3.98	—	0.25	1.64	—	—	—	1.47	0.75	15.24
Or.	5.27	1.49	6.22	1.93	5.72	2.84	4.74	5.92	7.11	5.23	6.36
Ab	27.00	29.43	29.37	30.29	30.05	26.97	30.96	31.37	32.28	31.11	30.79
An	26.33	23.96	17.17	17.53	14.37	17.06	18.07	14.07	14.26	19.52	15.54
Ne.	0.72	—	1.31	—	—	2.07	0.57	1.00	—	—	—
Di.	24.37	18.58	29.03	31.24	22.33	31.78	27.13	29.17	25.20	23.18	17.73
Wo.	—	—	—	—	—	—	—	0.37	—	—	—
Ol.	1.33	—	1.20	—	—	0.91	2.97	—	—	—	—
Hy.	—	9.79	—	4.09	2.28	—	—	—	1.15	5.41	—
Mt.	5.00	9.95	11.58	8.76	—	11.31	8.97	11.62	12.90	9.67	—
Hem.	5.09	—	—	—	15.70	—	—	—	—	—	11.19
Il.	4.17	2.06	3.21	4.94	0.32	6.02	5.49	5.44	4.61	4.15	—
Ti.	—	—	—	—	6.56	—	—	—	—	—	0.80
Ap.	0.72	0.78	0.91	0.97	1.01	1.04	1.10	1.04	1.02	0.98	0.66
Remarks Plag. is	An49	An45	An37	An37	An32	An39	An37	An31	An31	An39	An34

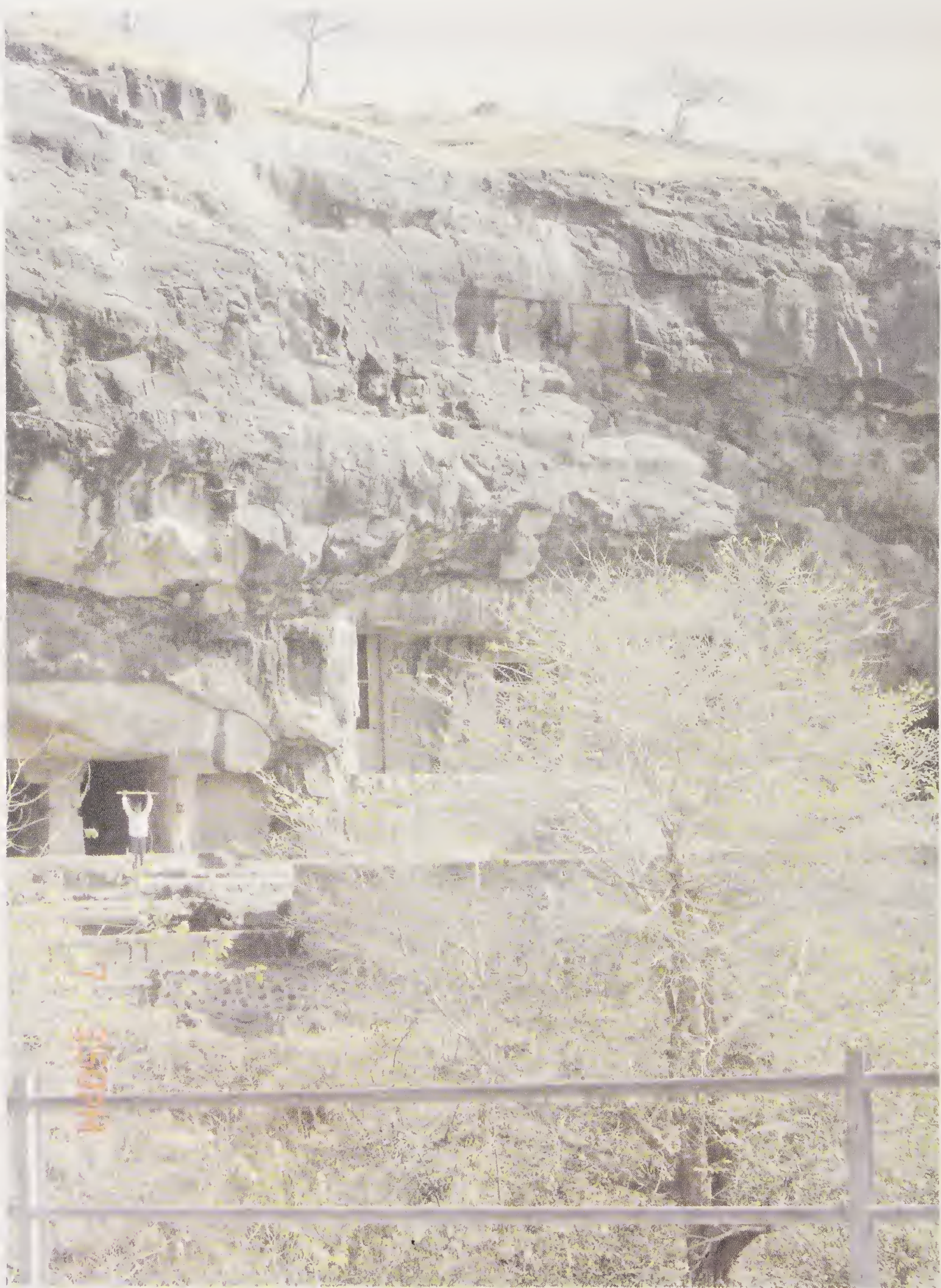


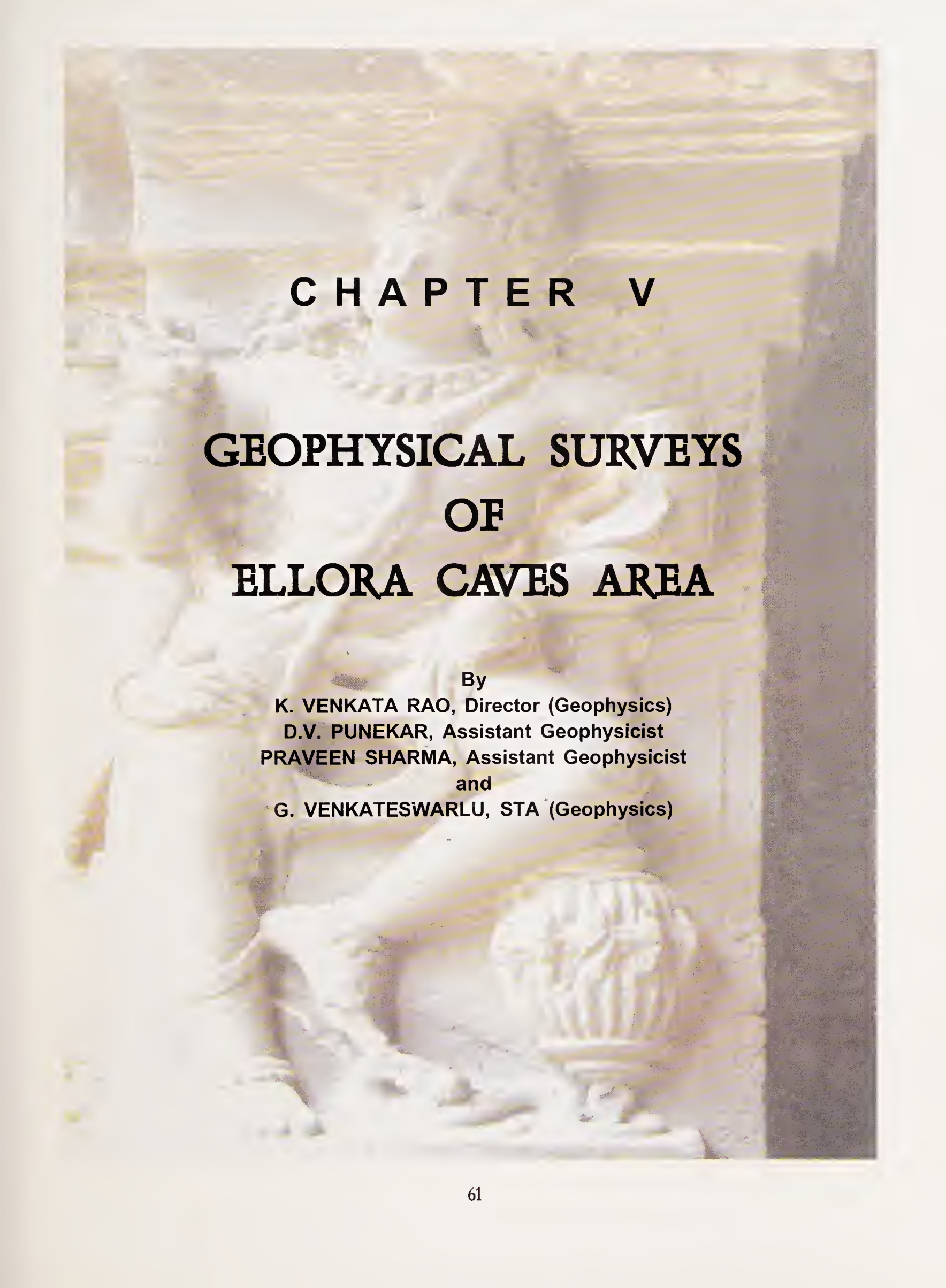
Table IV-4

**THE DIFFERENT INDICES AND RATIOS OF BASALT SAMPLES
FROM ELLORA CAVES AREA**

DI	33.00	34.90	36.90	32.47	37.42	31.88	36.27	38.29	40.86	37.09	52.38
SI	24.75	28.61	23.66	24.78	20.06	22.80	22.85	19.97	19.80	22.10	17.19
MI	69.14	65.65	70.42	70.20	75.57	72.69	71.58	75.05	75.28	72.49	77.22
FI	26.07	27.16	29.61	24.65	28.88	25.34	29.21	30.80	35.52	30.62	34.25
A	20.63	17.26	20.70	17.31	19.05	17.05	20.13	20.64	20.65	20.24	26.07
F	53.60	53.23	54.83	57.25	59.56	59.42	56.40	58.73	58.83	57.00	55.68
M	25.77	29.51	24.47	25.44	21.39	23.54	23.47	20.64	20.52	22.76	18.25
K/Na+K	0.21	0.07	0.22	0.08	0.21	0.12	0.17	0.20	0.24	0.19	0.23
Ca/Na+	2.84	2.68	2.38	3.06	2.46	2.95	2.42	2.25	1.98	2.27	1.92
F3/F2+	0.72	0.56	0.59	0.45	1.00	0.52	0.46	0.54	0.59	0.49	1.00

DI- Differentiation Index, SI- Solidification Index, MI- Mafic Index and FI- Felsic Index.



The background of the page is a sepia-toned photograph of the Ellora Caves. It shows intricate carvings of deities and figures in a cave setting. The text is overlaid on this image.

C H A P T E R V

G E O P H Y S I C A L S U R V E Y S

O F

E L L O R A C A V E S A R E A

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CHAPTER-V

GEOPHYSICAL SURVEY OF THE ELLORA CAVES AREA

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V. GEOPHYSICAL SURVEYS OF ELLORA CAVES AREA

INTRODUCTION

Geophysical surveys employing resistivity and shallow seismic methods have been conducted over the roof top areas of the Ellora caves to determine /map the zones of fractured/weathered rocks which may act as conduits for seepage of surface water inside the caves and destroy these heritages. The caves at Ellora stretch over a cumulative length of 2.5km and are aligned in an almost N-S direction at almost the same elevation. The top of the caves slopes at low gradients and at many places fresh rock is exposed without any soil cover. This has been a major constraint in planning the Geophysical survey in the area. Regular DC resistivity studies could not be taken up everywhere in the region. Thus, the options left has been the seismic refraction studies. In addition to this, reconnaissance resistivity surveys have been carried out by deploying the TVLF unit for the mapping of the resistivity pattern of the area above the caves. A total number of 4 traverses were laid in the region above the caves. The cumulative length of these traverses is 2.5 km. Regular DC resistivity studies in the area were however tried over some selected spots during the post monsoon period.

GEOLOGY

The Ellora cave area exposes two types of compound Pahoehoe basaltic lava flows. The thickness of these flows varies from 50 to 60m. They comprise of 15 to 18 pahoehoe units of varying thickness from 2 to 6m. The flow stratigraphy of the area is as follows

Top contact not exposed

Flow No. II: Compound Pahoehoe flow

Impersistent red bole / green bole horizon of 0.3 to 0.5m thickness

Flow No. I: Compound Pahoehoe flow

Bottom contact not exposed

A typical Pahoehoe unit comprises of top vesicular zone with a reddened crust and a ropy structure containing closely spaced sub rounded vesicles generally filled with silica and zeolites followed by middle massive part and thin bottom vesicular zone containing basal pipe vesicles. The massive parts of the units are fine-grained greenish grey to grayish in colour and are moderately to highly porphyritic. The massive parts at places are moderately weathered and at places highly weathered. No major tectonic joints are reported in the area. The units' show large scale cooling joints. There is a major valley relief joint seen in front of the caves trending N-S to N20° E to N20° W dipping 45° to 52° towards west.

GEOPHYSICAL SURVEY LAY OUT

The layout of the geophysical traverses of the Ellora cave area is presented in plate V-1. Traverses laid above the caves have been connected with the available survey triangulation points for the sake of geological correlation. Station interval along the traverse lines has been 5m. Traverses are separated by 15m. Two traverses, T-3 and T-4, of length 120 and 125 m each, are laid in the region above the caves 1 to 5. The nala depression between

cave 5 and 6 forms a gap area and no traverse could be laid because of flowing water and fresh rock exposure. Two parallel traverses T-1 and T-2, 300 and 315m long respectively are laid in the region above the caves 6 to 16, which are separated by 15m. The cave No.16 is an open one i.e. the Kailash temple area, and forms a break in the continuity of the traverses further north. However after cave 16, T-1 and T-2 traverses, have been continued with the same bearing to 630 and 680m further north, above caves 17 to 22. (Plate V-1). These traverses have been covered by both resistivity and seismic surveys.

METHODOLOGY

Reconnoitary resistivity survey using TVLF unit has been done during the pre-monsoon period to understand the fracture pattern along the traverse lines discussed above along with seismic refraction surveys. During the post-monsoon, regular DC resistivity studies have been conducted by deploying the Dipole-Dipole array with dipole length of 5m from 1 to 5 levels (N=1 to 5). The velocity and conductivity parameters of these rocks have been determined for detection of any joint/fracture.

INSTRUMENTS

The instruments deployed for the present survey are tabulated below:

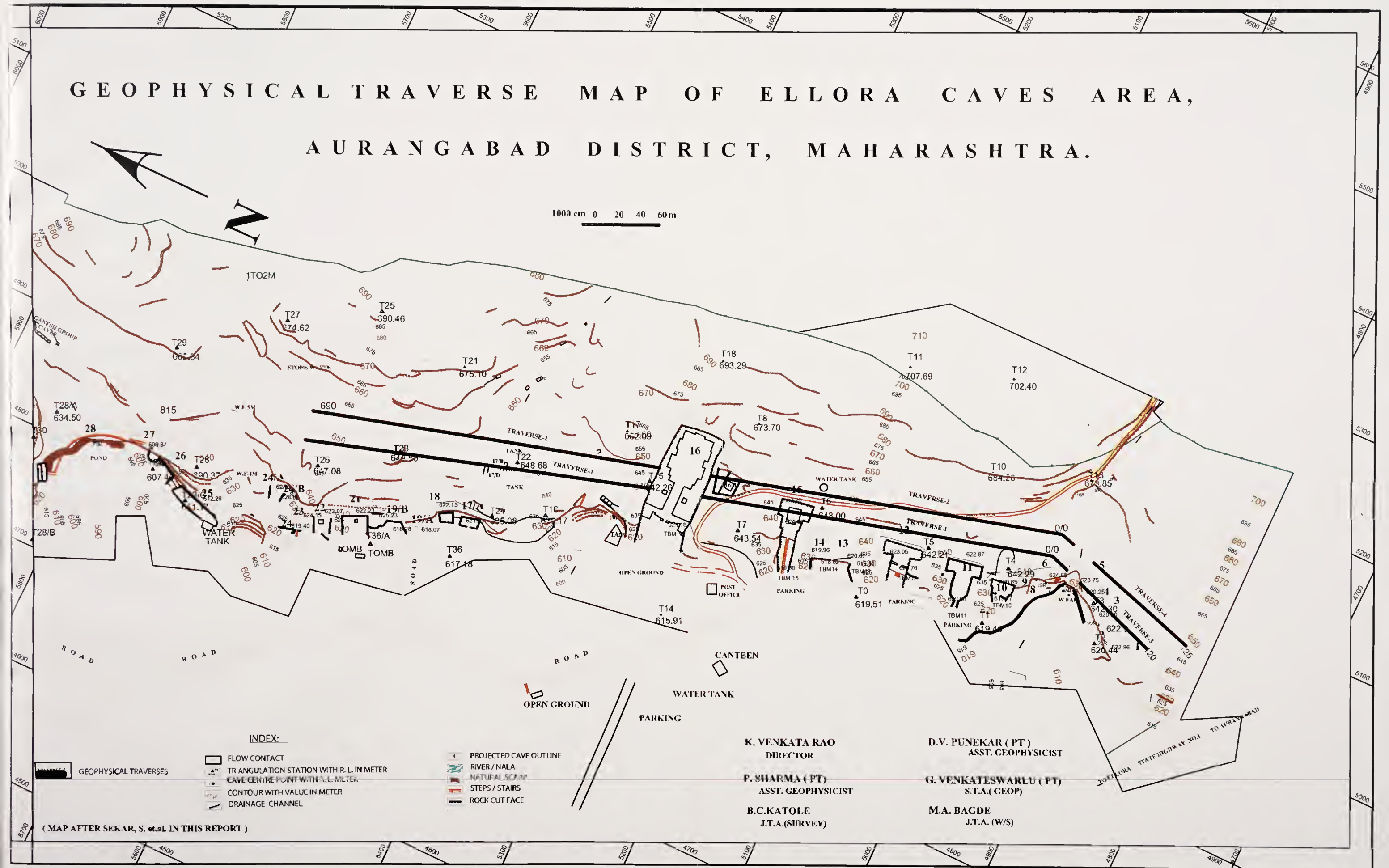
SINo	DESCRIPTION OF METHOD	DETAILS OF INSTRUMENTS
1	Seismic Refraction Methods	Signal Enhancing Seismic Refraction unit of Geometrics
2	Resistivity Methods	1. TVLF Unit and 2. DDR2 Resistivity potentiometer
3	Survey	Theodolite

STATISTICS

The statistical details of the area are as under:

Sl. No.	Description	Details
1	Length of Traverses Laid	2.2km
2	Line Km Covered By Resistivity Surveys	2.2km
3	Line Km Covered By Seismic Surveys	2.2km
4	Line Km Repeated During Post Monsoon Period.	2.2km

GEOPHYSICAL TRAVERSE MAP OF ELLORA CAVES AREA, AURANGABAD DISTRICT, MAHARASHTRA.





RESULTS

Pre-monsoon Resistivity Profiling (TVLF Surveys)

The results of pre-monsoon resistivity studies carried out in the Ellora caves area, deploying the TVLF unit is presented in Plate V-2 and 3. The region above the caves 1 to 5 is covered by traverse T-4 (Plate V-2). The zone between stations 5 and 40 shows higher order resistivities ranging up to 100-Ohm m except over stations 10 and 25. A conductive zone with resistivities of the order 10 to 15 Ohm m is interpreted in the zone between stations 50 and 85. This zone is situated just above the caves 3 and 4. The zone away from this has indicated resistivities of the order of 30 to 50 Ohm m. This is suggestive of some permeable conduits/ fractures /fractures on either sides of the conductive zone. The interpreted fractures are shown in the figure. The results along traverse T-3 have also indicated some fractures (Plate V-3). Fall in resistivity, of the order of 20 - 40 Ohm m beyond station 60 is noticed along this traverse.

The resistivity profile along traverse T-2 in the region above caves 6 to 22 is shown in Plate V-4. Various conductive horizons and saturated with water have been shown on this figure.

Post-Monsoon Resistivity profiling (DDR2 Surveys)

The post monsoon resistivity studies in the area are carried out by regular DC resistivity studies deploying the instrument DDR2, along the same traverses. The electrical pseudo sections arrived at from Dipole - Dipole arrays are presented in Plates-V-5 to V-8. The results along traverse T-4, over the caves 1 to 5, show a resistive zone between stations 0-30. The area between stations 35 to 40 has reflected a conductive zone with order of resistivities ranging between 10 to 30 Ohm m.

Between stations 65 and 75, a conductive zone is recorded wherein same possible fracture has been inferred between stations 70 to 72. This correlates with the data of TVLF during the pre-monsoon period (Plate V-2), and the zone is more defined. Similar zone of low resistivity has been indicated between stations 85 to 90 suggesting likely-hood of seepage in the caves 1 to 5.

The Electrical pseudo section along traverse T-3 is shown in Plate V-6. The zone between stations 55 and 68 shows resistivities of the order 65 to 90 Ohm m and the zone between stations 75 to 85 has shown a conductive formation which is flanked on either sides by a resistive zone, extending downward thus suggesting presence of possible fractures on either flanks of the resistive zone. Another conductive zone has been indicated in the region between stations 96 to 100 at the top, which is flanked by conductive zones on either sides and below it. This suggests presence of fractures in the zone, which may be responsible for the seepage and saturation at depth. A look into the disposition of these conductive zones along these two traverses suggests a fracture pattern orthogonal to the trend of caves 1 to 5.

The electrical pseudo section along traverse T-2 is presented in plate V-7. The resistivity pattern along this traverse indicates two conductive zones with order of resistivities 5 to 30 Ohm m, the first one between stations 20 and 60 and the second one between stations 115 and 130. Two more conductive zones with limited extent were indicated near stations 80 and 100. Another narrow zone of low resistivity has been traced on the fringe near stations 195 to 197. The zone between stations 20 to 60 occurs in the region above caves 8 to 10 and the one between stations 115 and 130 occurs in the region above cave 12.

Plate : V-2

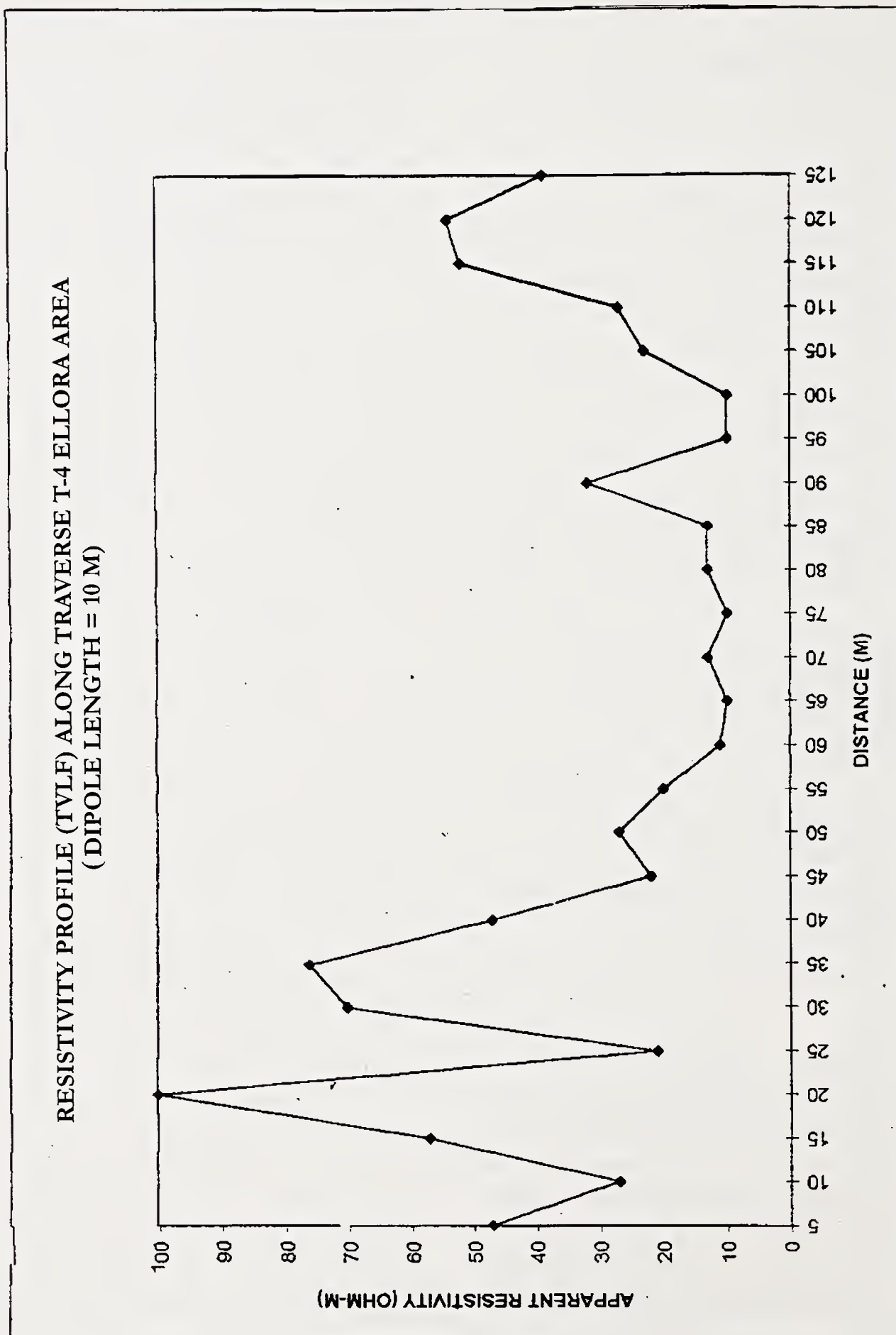


Plate : V-3

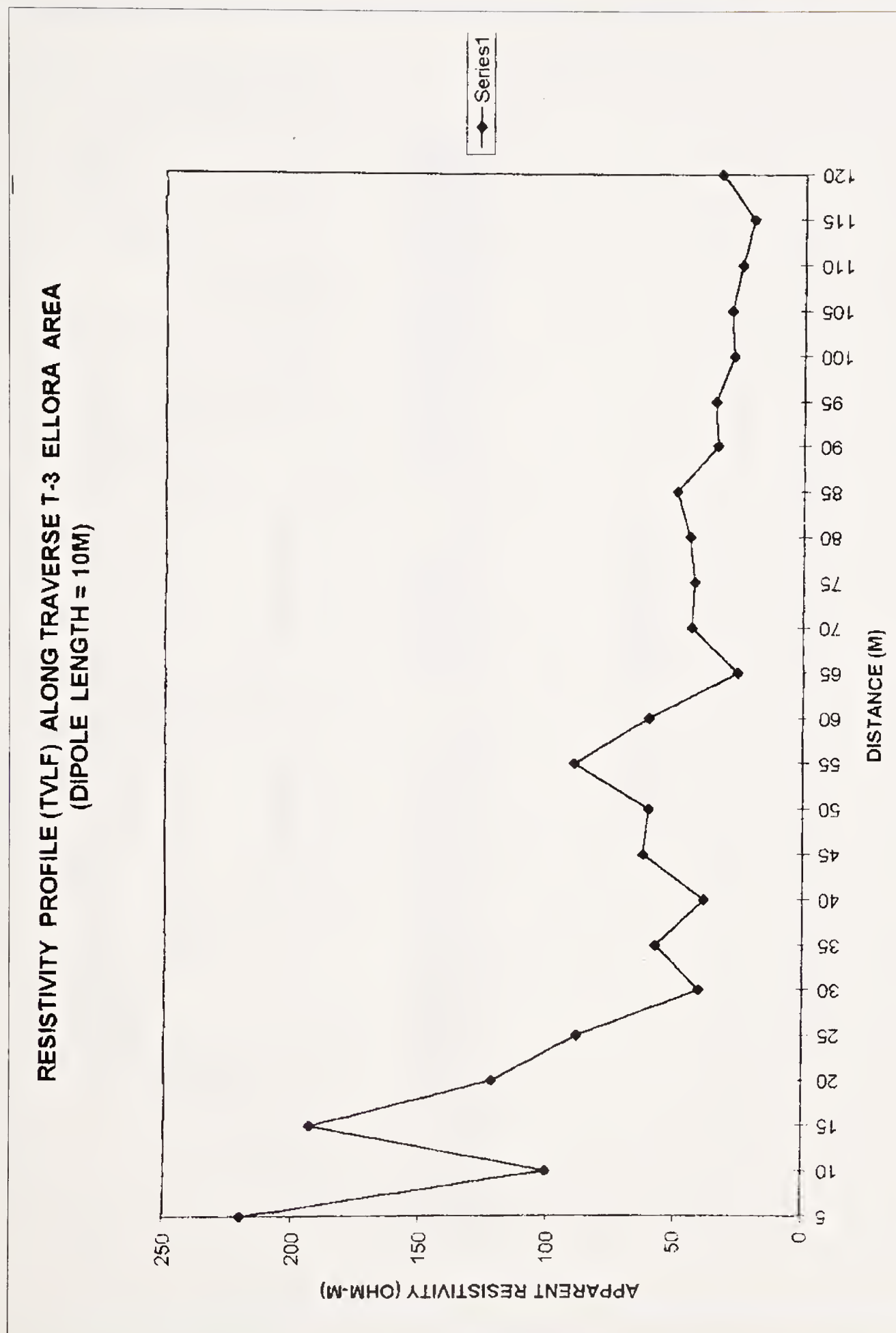


Plate : V-4

RESISTIVITY PROFILE (TVLF) ALONG TRAVERSE T-2, ELLORA AREA

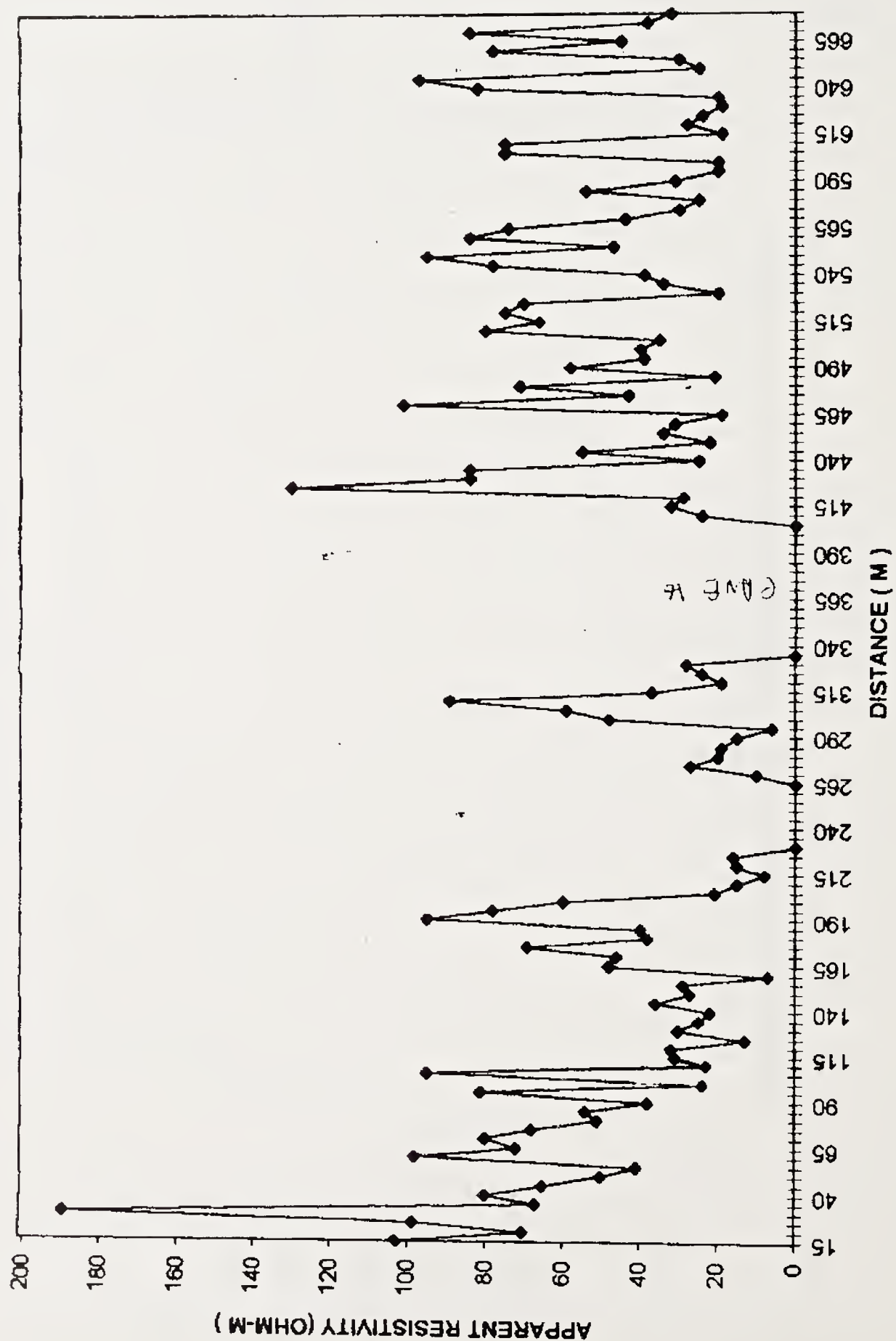


Plate : V-5

ELECTRICALPSEUDO SECTION ALONG TRAVERSE,T -4 ABOVE CAVES 1 TO 5 ELLORA CAVES AREA, MAHARASHTRA

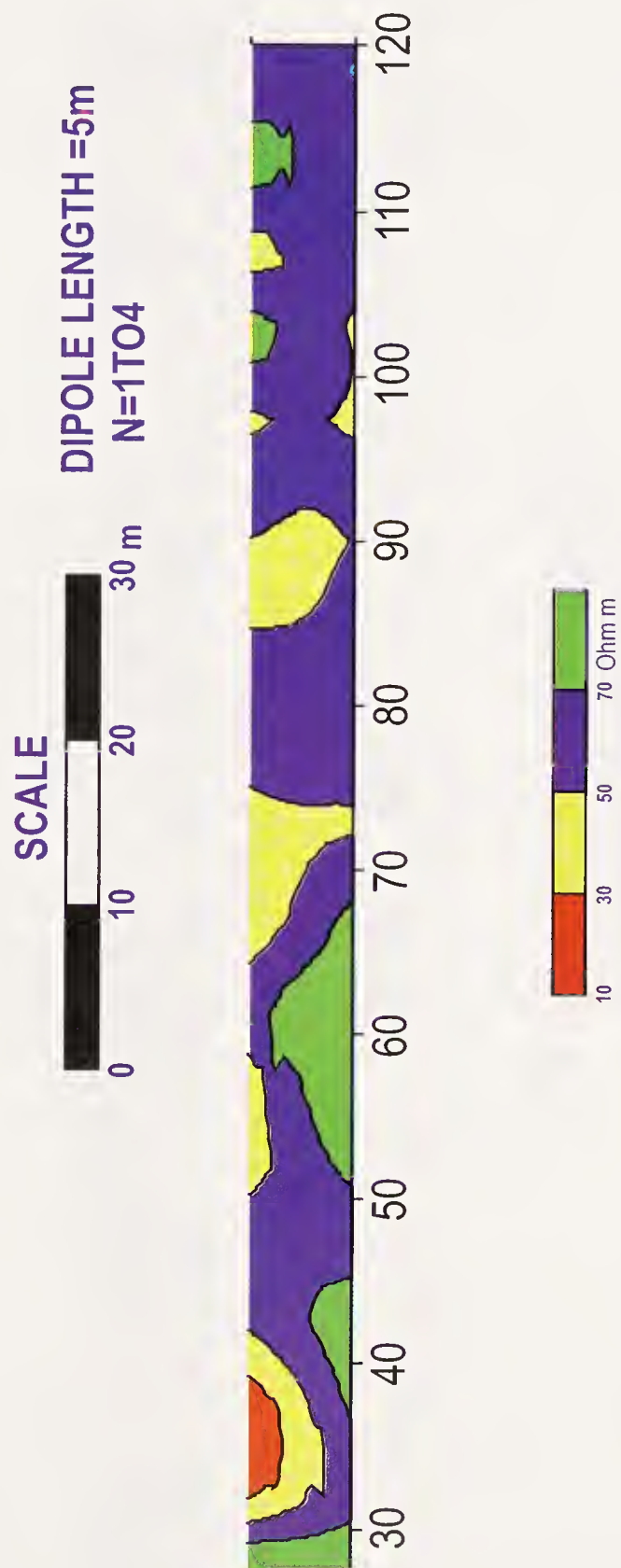


Plate : V-6

**ELECTRICAL PSEUDO SECTION ALONG TRAVERSE-3
ABOVE CAVES 1 TO 5
ELLORA AREA , MAHARSHTRA**

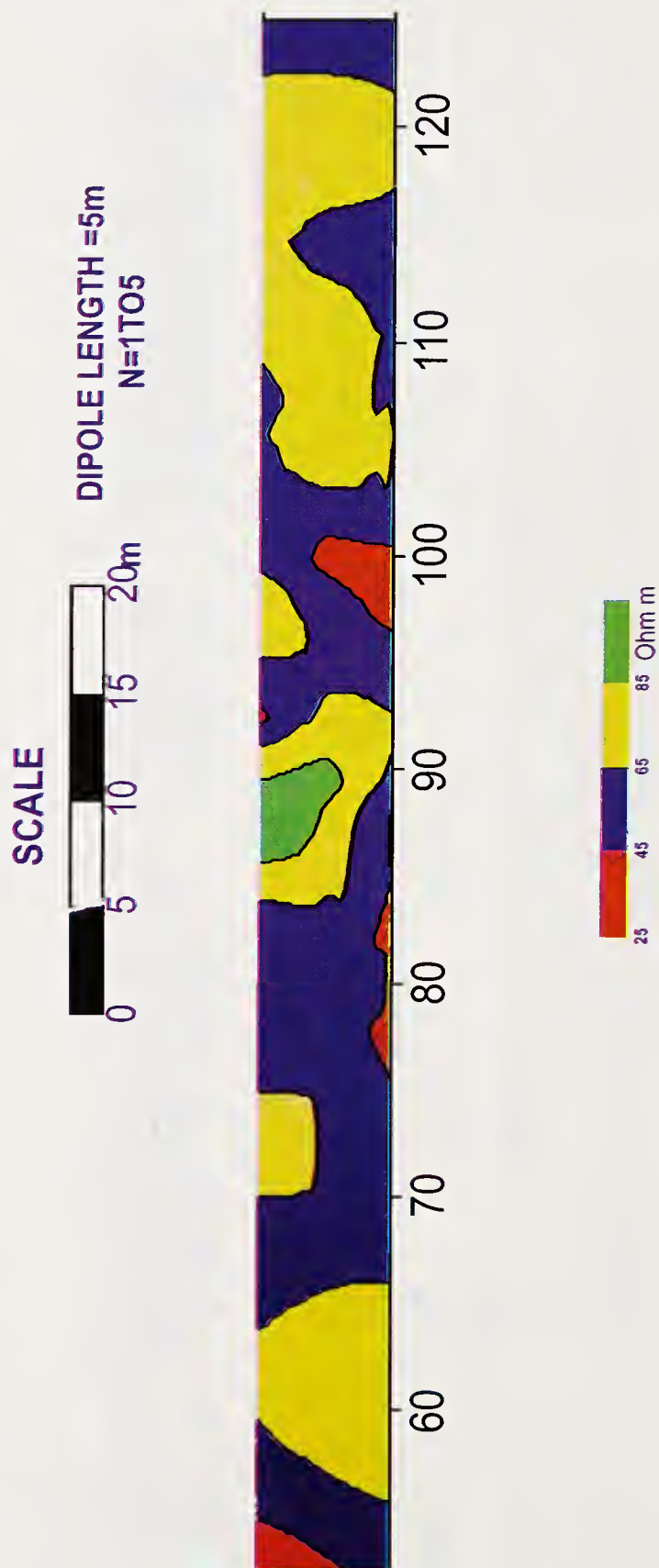


Plate : V-7

**ELECTRICAL PSEUDO SECTION ALONG TRAVERSE T-2
ABOVE CAVES 6 TO 15
ELLORA CAVES AREA MAHARASHTRA**

SCALE



**DIPOLE LENGTH = 5 m
N=1 TO 3**





The presence of conductive zones around stations 80 and 100 may suggest some parallel fracture pattern in the area.

The electrical pseudo section between stations 480 to 640, in the region above caves 17 to 22, along traverse T-2 is presented in Plate V-8. It brings out two conductive zones in the area one around stations 600 and the other between 630 to 638. Relatively low order conductive zone has been picked up near station 540 which does not show depth continuity. Thus the results show the presence of fractures around these specified zones near stations 600 and 630. The results along the parallel traverse T-1 in this region have also indicated similar picture. (Plate V-10)

The electrical pseudo section along traverse T-1 (Plate V-9) extends for over 200m. The zone between stations 20 and 50, indicates low order resistivities of 20 to 60 Ohm m. The second zone of low resistivity has been indicated between stations 80 to 100 and third between 175 to 190.

In addition to these, thin zones of low resistivity have been noticed near stations 120 and 75. The zones between 100 to 120 and 140 to 170 have indicated higher resistivity of 90-Ohm m and above.

Correlation of the results along these two traverses shows that the conductive zone has continuity in the zone between stations 20 to 60 in both the traverses. Similar is the case with the zone near station 120. Disposition of the conductive zones along these two parallel traverses confirms the continuity of the fractures, which forms the source for percolation of water through fractures in to the caves.

Seismic Refraction Surveys

Seismic refraction surveys were carried out to record the subsurface velocity distributions in the region above the caves along the traverses laid for resistivity surveys. The data is presented in Table V-1 and Plates V -11

Table-V-1

TABLE SHOWING THE VELOCITY PATTERN ALONG TRAVERSE T1 AND T2

Sl.No.	DESCRIPTION OF TRAVERSE	STATION (FW/RE)	V1 (Km/sec)	V2 (Km/sec)	V3 (Km/sec)	V4 (Km/sec)
1	T1	0-60(FW)	3.05	-	-	-
2	T1	60-120(RE)	2.5	-	-	-
3	T1	60-120(FW)	2	-	-	-
4	T1	120-60(RE)	2	-	-	-
5	T1	110-170(FW)	1.4	4	4.5	-
6	T1	170-110(RE)	0.4	4	-	-
7	T1	170-230(FW)	2.2	-	-	-
8	T1	230-170(RE)	2	-	-	-
9	T1	460-500(FW)	2.03	-	-	-
10	T1	500-460(RE)	1.8	3	-	-
11	T1	500-560(FW)	2.1	-	3.7	-

12	T1	560-500(RE)	5	2	-	-
13	T1	560-620(FW)	5	2	-	-
14	T1	620-560(RE)	5	2	-	-
15	T1	620-680(FW)	5	3.6	-	-
16	T1	680-620(RE)	5.2	2.5	-	-
17	T2	0-60(FW)	1.76	5	SF	5.4
18	T2	60-0(RE)	2.85	-	-	-
19	T2	80-140(FW)	0.4	2.5	5	-
20	T2	140-80(RE)	0.4	3.3	-	-
21	T2	140-200(FW)	3.7	3.6	-	-
22	T2	200-140(RE)	1.5	5	-	-
23	T2	200-230 (FW)	3.9	-	-	-
24	T2	230-200(RE)	3.9	-	-	-
25	T2	265-315(FW)	1.53	-	-	-
26	T2	315-265(RE)	1.8	-	-	-
27	T2	460-530(FW)	2.7	S	3.5	-
28	T2	530-460(RE)	4	2.5	-	-
29	T2	525-585(FW)	1.5	5.5	S	4.5
30	T2	585-525(RE)	2.3	-	-	-
31	T2	585-640(FW0	2.3	5.5	-	-
32	T2	640-585(RE)	3	-	-	-
33	T2	645-685(FW)	5	3	-	-
34	T2	685-645(RE)	3.5	4	-	-

n.b.: S= Shift

The seismic profile along traverse T-3, above the caves 1 to 5 (Plate V- 11), where the surface layer has indicated a velocity of 2.5 km/sec, a shift in the segment, with a low velocity layer of 1.5 km/sec, followed by a third layer showing velocity of 5.5km/sec. This suggests a fracture in the region, which has been indicated by a shift in the velocity segment. The reverse shot has indicated a surface layer velocity of 4 km/sec followed by a shift below which a layer of velocity of 1.42 km/sec has been indicated. The depth could not be estimated as the inversion in velocity problem was encountered. The traverse T-4, which is parallel to T-3 over the

caves 1 to 5, has shown the surface layer having a velocity of 2.2 km/sec followed by a low velocity layer at depth. Reverse shot shows a surface layer velocity of 2.8 km/sec, followed by a layer velocity of 5 km/sec at depth. This anisotropy in the velocity pattern suggests the heterogeneity in the region from the ground surface to cave roof. Similar inhomogeneity, though not one to one correlatable ; has been seen from the resistivity data also.

The region above the caves 6 to 15 was covered by two traverses T-1 and T-2 of 200 and 230 m length respectively. T-1 is shown only up to 60 m. rest of

Plate : V-8

**ELECTRICAL PSEUDO SECTION ALONG TRAVERSE T-2
ABOVE CAVES 17 TO 22
ELLORA CAVES AREA, MAHARASHTRA**

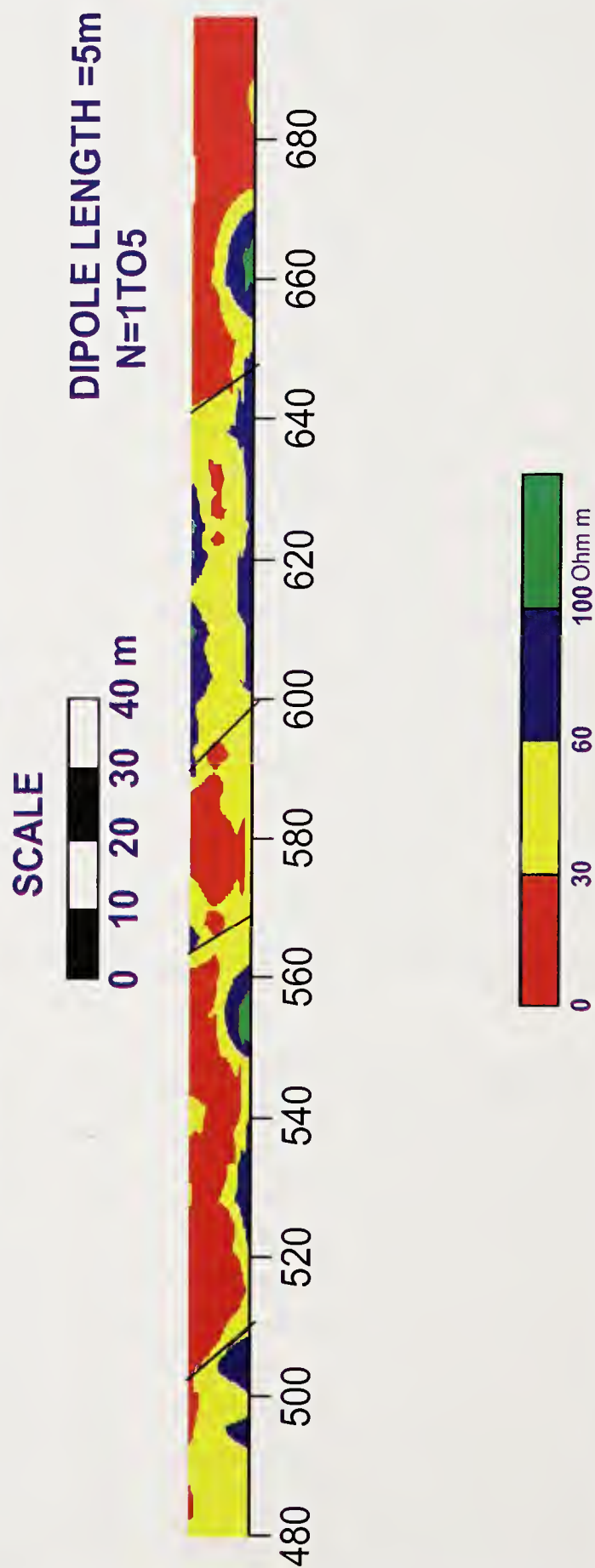


Plate : V-9

ELECTRICAL PSEUDO SECTION ALONG TRAVERSE-T-1 ABOVE CAVES 6 TO 15 ELLORA CAVES AREA, MAHARASHTRA

SCALE  **DIPOLE LENGTH = 5m**
N=1 TO 5

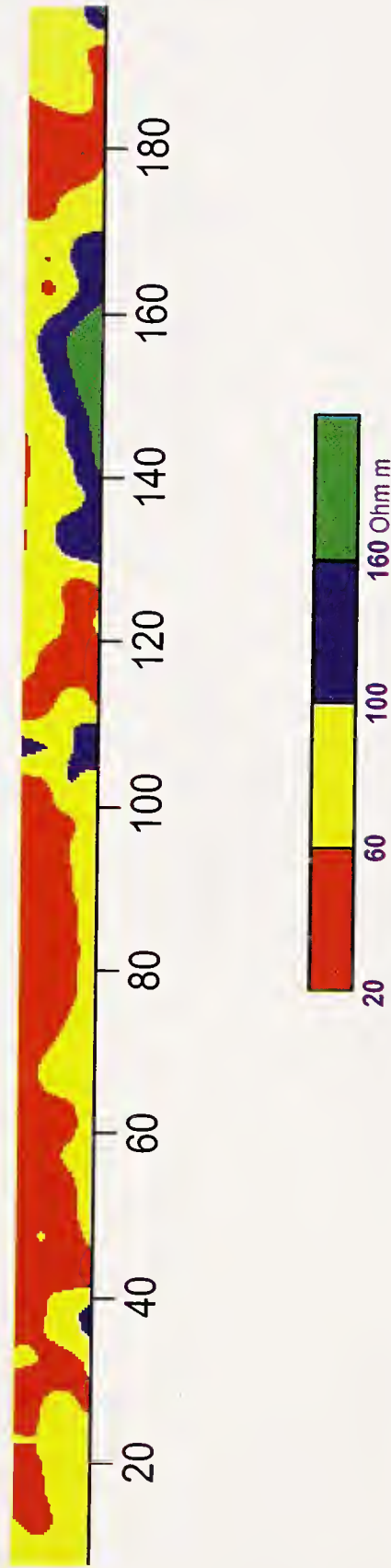


Plate : V-10

**ELECTRICAL PSEUDO SECTION TRAVERSE T-1
ABOVE CAVES 17 TO 22
ELLORA AREA**

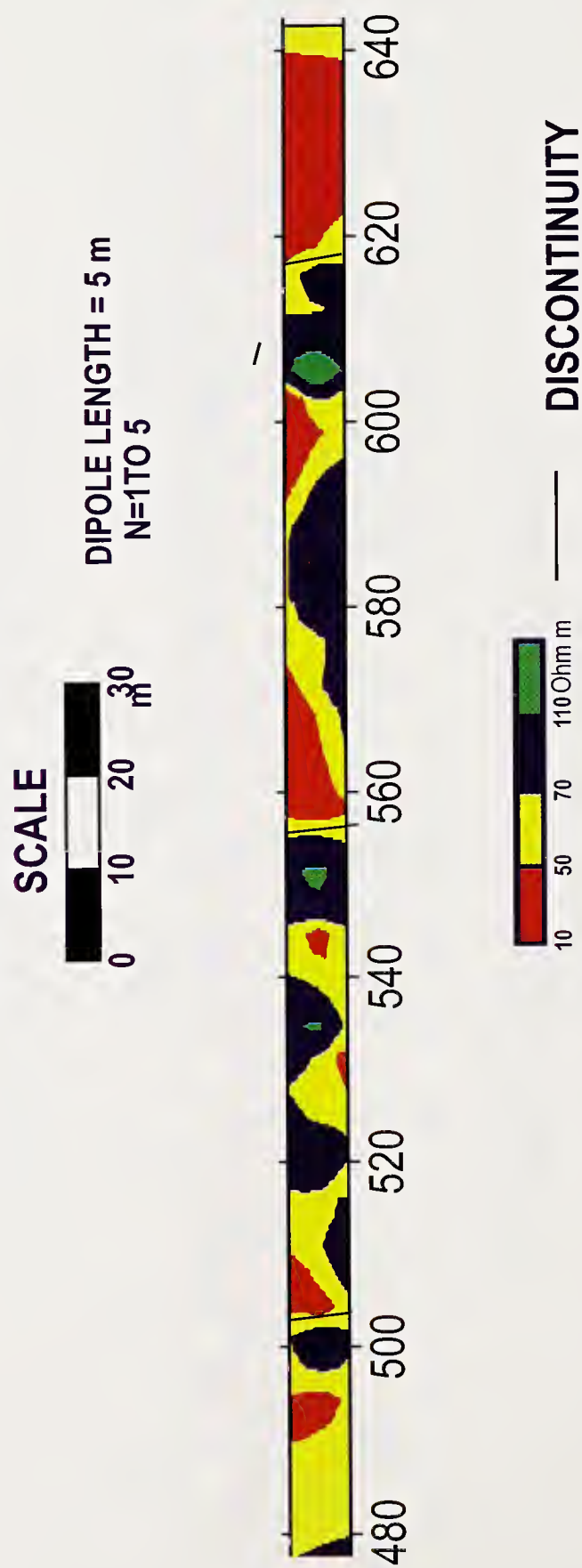
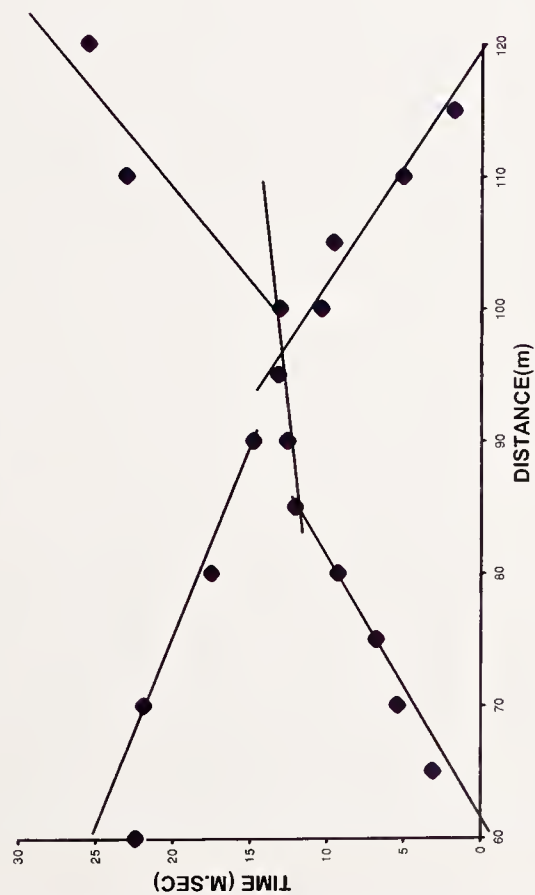


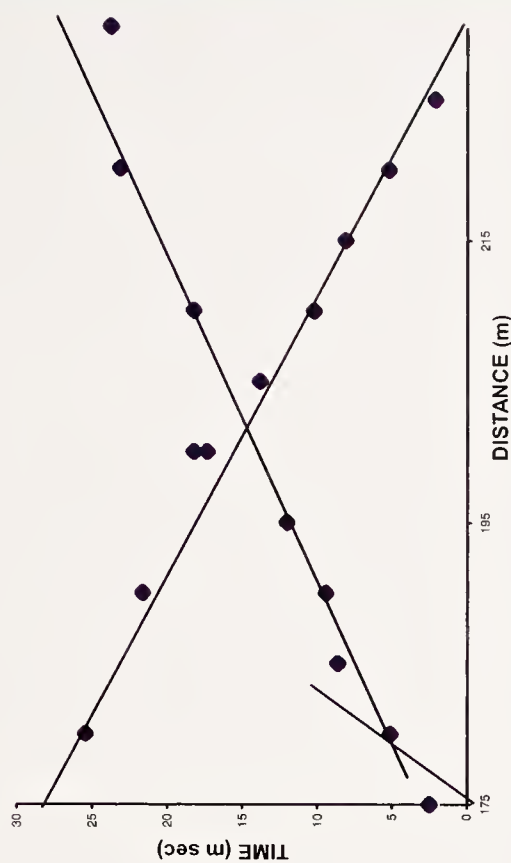
Plate : V-11

REPRESENTATIVE SEISMIC PROFILES ELLORA CAVES AREA, MAHARASHTRA

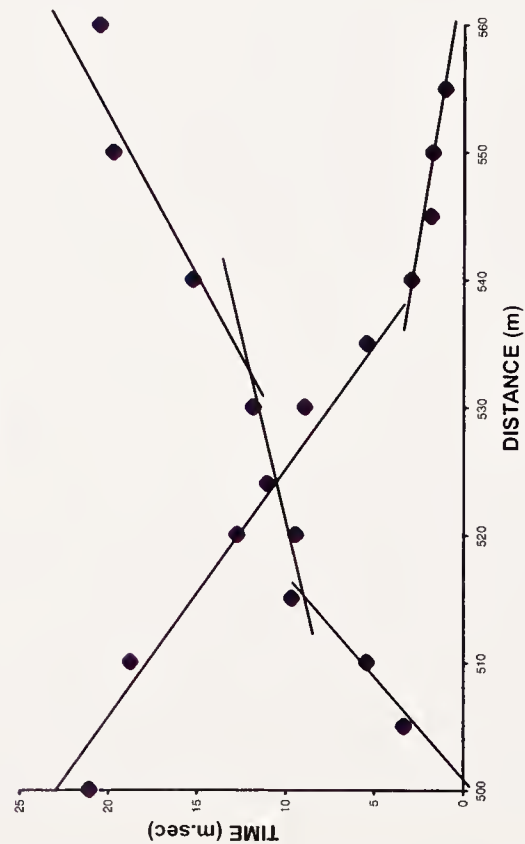
TRAVERSE T-1



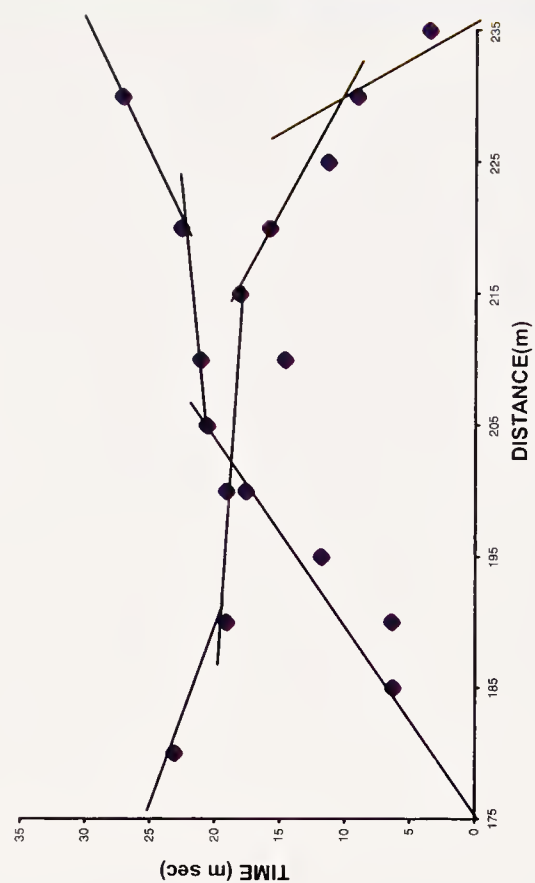
TRAVERSE T-1



TRAVERSE T-1



TRAVERSE T-1AM





it is shown in plate V-11. T2 is shown only between (170-230) m. The velocity intercepted in the zone shows a 3 km /sec layer at the top extending to depth. The reverse shot has shown surface layer velocity of 2km /sec extending to depth. There are no velocity distortions in the area but the velocity range indicates that the flows in the zone are highly weathered as indicated by lower velocities. Similar is the case in the shot between stations 60 to 120 where the velocities indicated are of the order of 2 to 2.5km/sec on both the directions. The shot between stations 110 and 170 has shown a departure from the previous stretch where the surface layer has indicated a velocity layer of 1.4km/sec followed by a velocity layer of 5 km/sec and at depth the layer shows velocity of 4km/sec. The reverse shot has shown almost a single layer case with layer velocity of 4km/sec. This type of anomaly suggests the possibility of presence of fractures in the region. The segment between stations 170 to 230 have indicated a layer velocity of 2.2 km /sec in the forward shot and 2km /sec in the reverse shot. This indicates layer homogeneity; but the flows are weathered. The zone between stations 260 to 320 between caves 15 and 16 in the forward shot direction has indicated the surface layer velocities of 1.66 km/sec and with a shift in the layer velocity to 5km/sec at depth. The reverse direction shot shows a 1.66km /sec velocity layer on the top followed by 4.5 km /sec layer at depth.

The section of the traverse T1 and T2 between stations 460 and 500 shows surface layer velocity of 2.05 km/sec and continues to depths. The reverse shot shows a layer velocity of 1.8 km/sec for the surface and at depth a layer velocity of 3 km/sec has been intersected showing a variation, which may be attributed to the heterogeneity, may be a fracture or a unit contact. The zone between

stations 500 and 560 has indicated in the forward direction shot a surface layer velocity of 2.1 km/sec followed by a 3.7-km/sec-layer velocity at depth. The reverse direction shot shows the high velocity layer of 5 km/sec on the surface followed by a layer of velocity of 2km/sec at depth, suggesting a discontinuity/contact in this zone, possibly because of a contact between two flows. The section of the traverse between stations 560 and 620 has indicated a layer velocity of 5km/sec for the surface and a low velocity layer of 2 km/sec at depth. In the reverse shot the surface layer has velocity of 5 km/sec and 2-km/sec-velocity layer at depth. Similar is the case for the section between stations 620 and 680 where the surface layers show high velocities and inversion at depth.

The results along the traverse T-2 are tabulated in Table-V-1. It shows similar features and suggests continuity of the fracture zones across the traverse lines. The surveys were repeated in the post monsoon period. The results show an increase in velocity ranges by 20 to 30 % and thus confirming presence of saturation through some fractures.

CORRELATION OF RESISTIVITY AND SEISMIC SURVEY RESULTS

A broad correlation can be seen in the results of the seismic and resistivity surveys. The seismic survey results along traverse T-3 and T-4 have shown shifts in the velocity segments. These can be correlated with the conductive zones picked during the pre monsoon and post monsoon studies. Thus it can be concluded that the fractures responsible for the seepage have the geophysical manifestations on the top of the caves in the region. The area between caves 10 and 12 has also shown conductive zones between stations 30 and 60 and the seismic study has shown the shift along the reverse direction shot. Similarly the region of

conductive zone recorded between 100 and 120 stations shows a shift in the velocity segments. This can be correlated to the presence of possible fractures.

The region between cave 15 and 16 was studied in detail by mapping the equi-potential lines in the area. This has correlation with seismic results obtained.

The region between caves 17 to 22 have shown a correlation with a discontinuity shown in both the resistivity and seismic survey results, where higher order surface velocities beyond stations 540 have been indicated as compared to that of the stations up to 540. The resistivity studies also show the presence of discontinuity in the area.

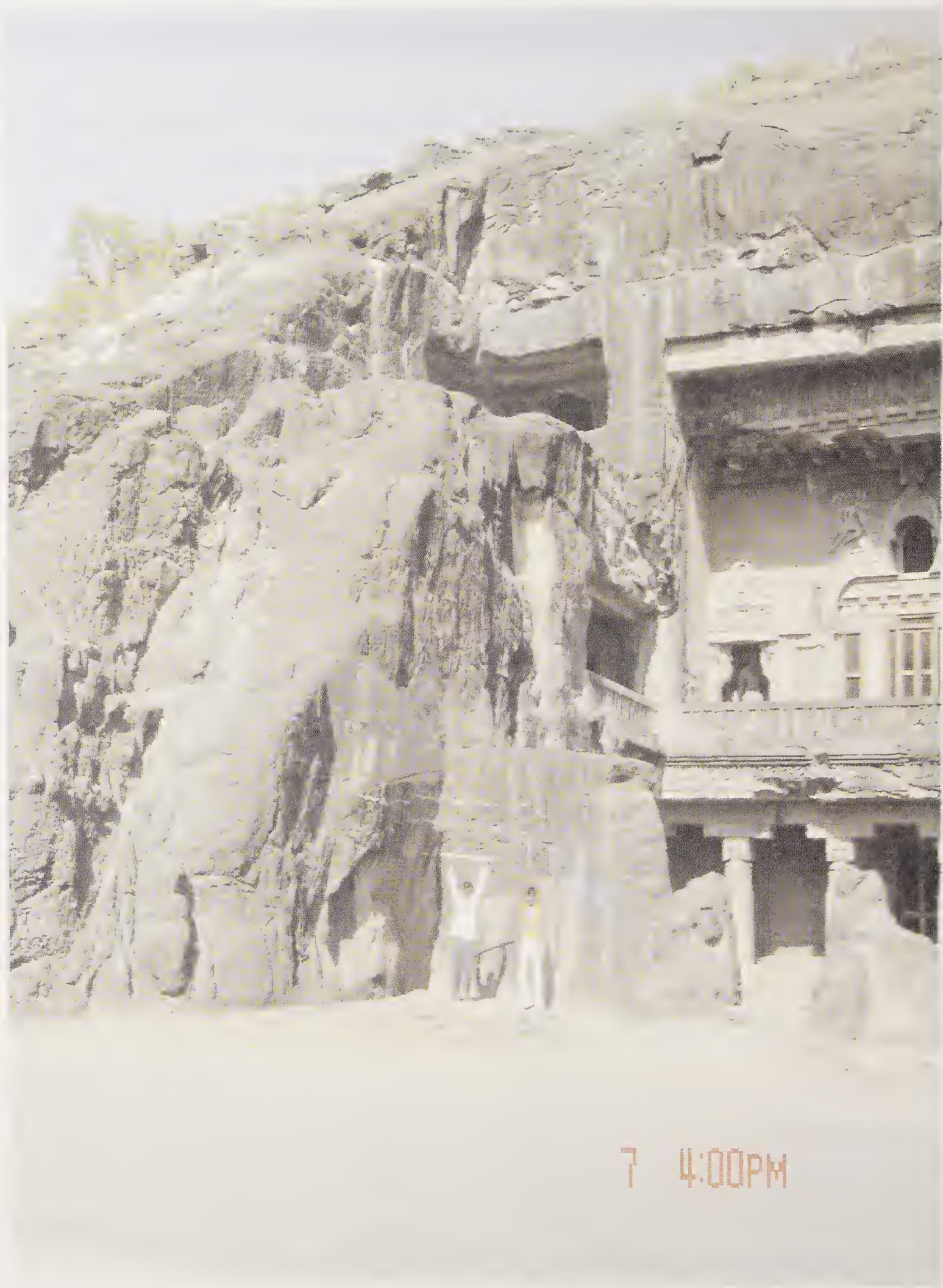
CONCLUSIONS AND RECOMMENDATIONS

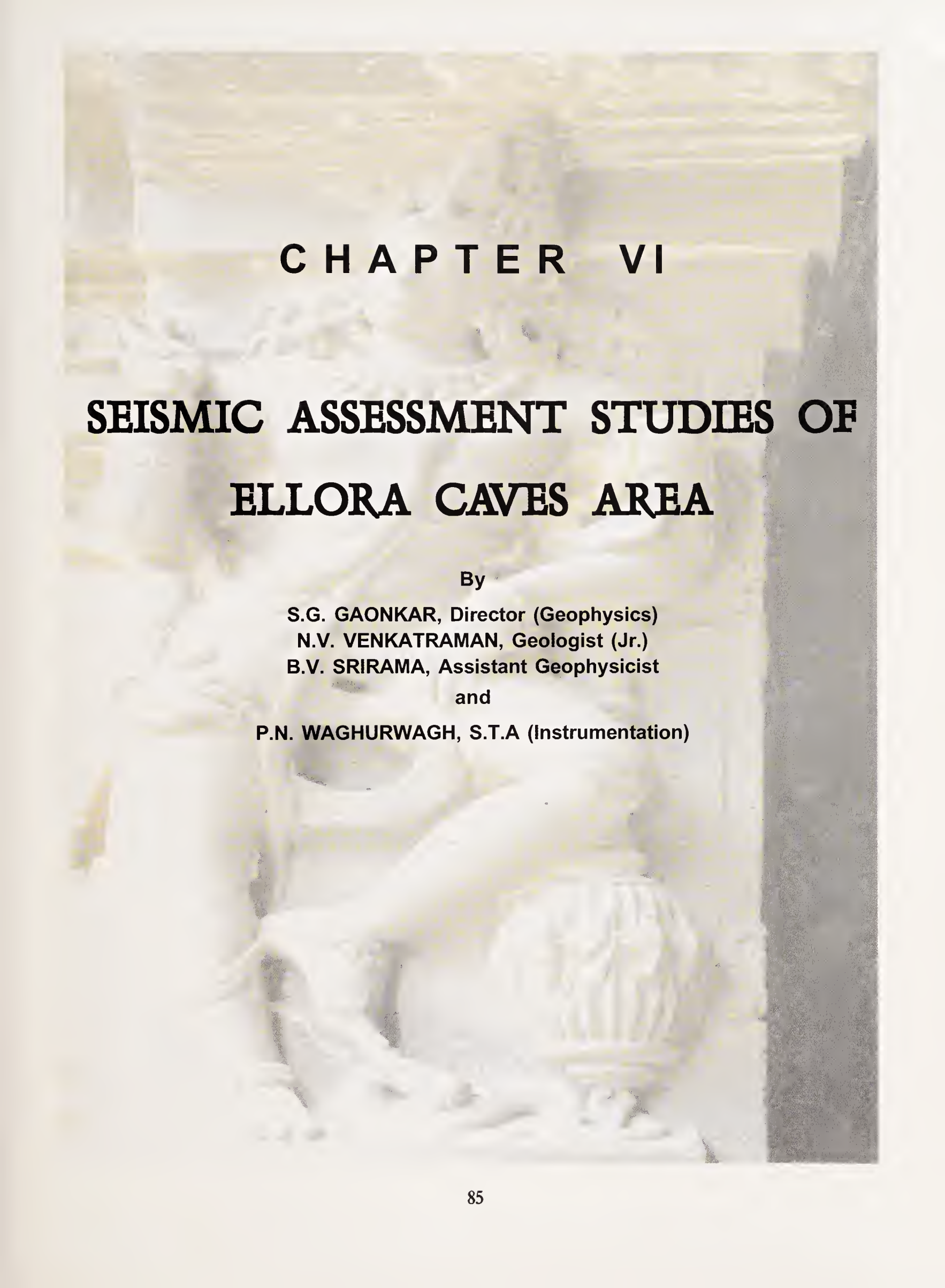
The results of the geophysical studies carried out in the Ellora cave area have been influenced mainly by the fresh rock exposure. The resistivity surveys results when correlated with the qualitative interpreted results of seismic refraction studies, for both pre monsoon and post monsoon period bring out the possible fracture pattern in the region. The zones of interest have been tabulated in table V-2.

These conductive zones should be correlated with the other geological inferences and suitable remedial measures may be undertaken to preserve these monuments.

Table-V-2

Sl.No	Description of zones (stations)	Cave Number	Resistivity order
1	Traverse T-3 (75-85) (95-100)	1 to 5	10 to 20 Ohm m
2	Traverse T-4 (35-40) (65-75)	1 to 5	30 to 40 Ohm m
3	Traverse T-1(20-60) (175-90)	6 to 12	10-40 Ohm m
4	Traverse T-2 (20-60) (115-30)	6to12	5 to 30 Ohm m
5	Traverse T-1 (600-640)	17to 19	30-50Ohm m





C H A P T E R V I

SEISMIC ASSESSMENT STUDIES OF ELLORA CAVES AREA

By

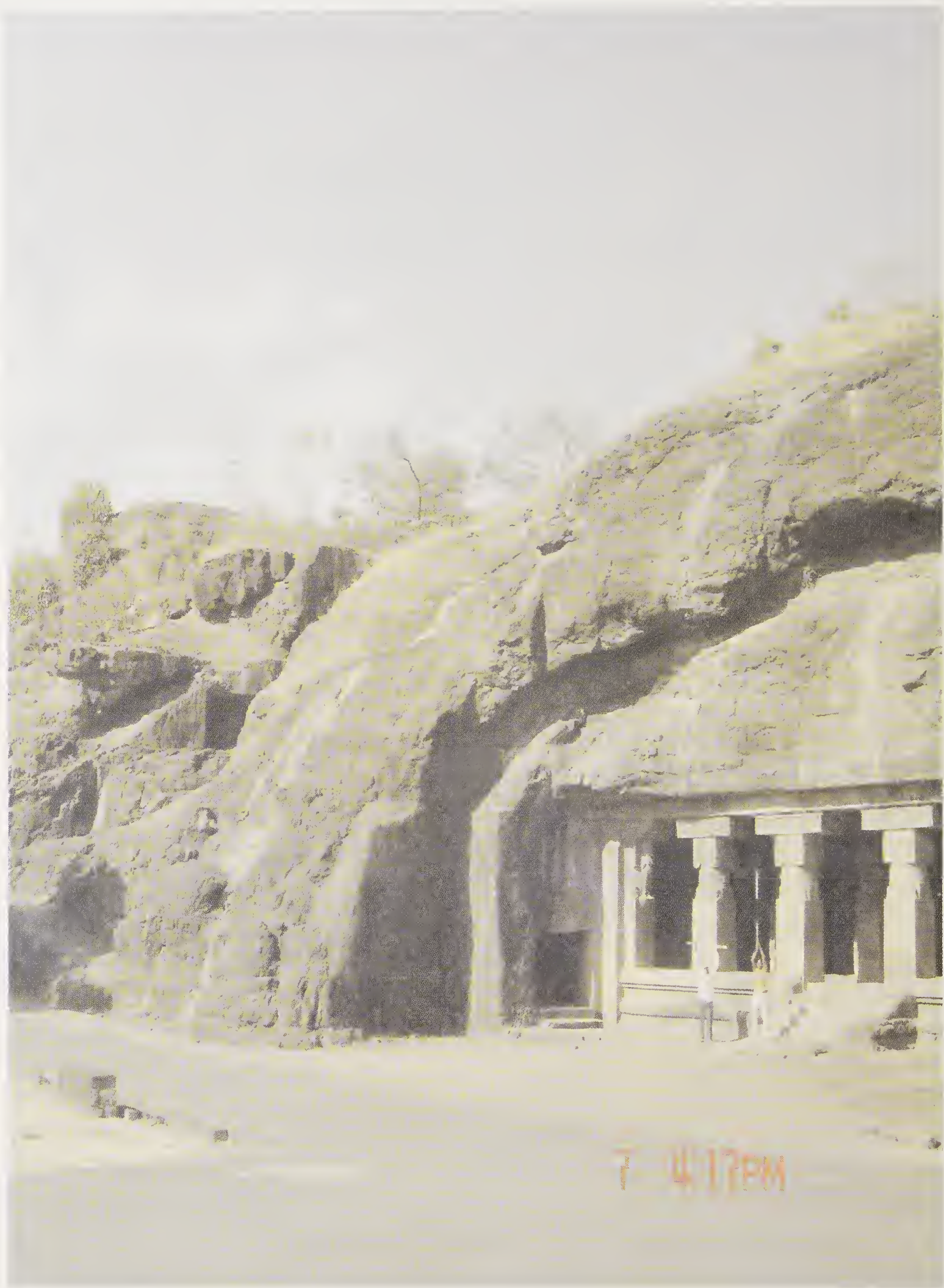
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CHAPTER-VI

SEISMIC ASSESSMENT STUDIES OF ELLORA CAVES AREA

CONTENTS

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VI. SEISMIC ASSESSMENT STUDIES OF ELLORA CAVES AREA

The rock cut caves at Ellora ($20^{\circ} 2' N$; $75^{\circ} 10' E$; 46 P/4) are located about 30 km from Aurangabad, on Aurangabad - Kannad road (Plate VI-1). These caves have been carved in one of the most seismically rigid zone of Deccan Syncline. The area is located on the Maismal plateau and comprises morpho-units such as plateau, residual hill, valley slope and valley. The hills rise to about 900-980 m above msl, from the surrounding plains at around 600m above msl, thus giving a relief of about 350 m. The slopes are moderate to steep, with intermittent scarps at places. It forms a part of Shivna sub basin of Godavari Basin. Details of morphometric and structural features of the area are discussed in chapters II, III, and IV.

The area has not been subjected to any prominent seismic acceleration in the recent past. The nearest historical earthquake of the magnitude of 4.3 Ms was located at Nasik about 150 km. The cave structures as such, do not bear any signatures of damage by earthquake in the past. However, this being the world heritage monument, it would be appropriate to assess the seismic hazard and seismic risk ensuring the resistance to expected peak ground seismic accelerations. In the present document the seismic data of the area is presented. The data has further been analysed for assessment of the seismic hazard potential of the cave domain. In this chapter the seismic hazard potential of the cave domain has been discussed and further studies to assess the seismic risk are outlined.

METHODOLOGY

For the objective enumerated above the following studies have been conducted:

- Review of regional seismicity and major seismogenic lines
- MEQ studies
- Evaluation of seismic hazard, following the deterministic approach
- Surface noise survey

SEISMOTECTONICS

1. Regional Seismicity and Major Seismogenic Lines

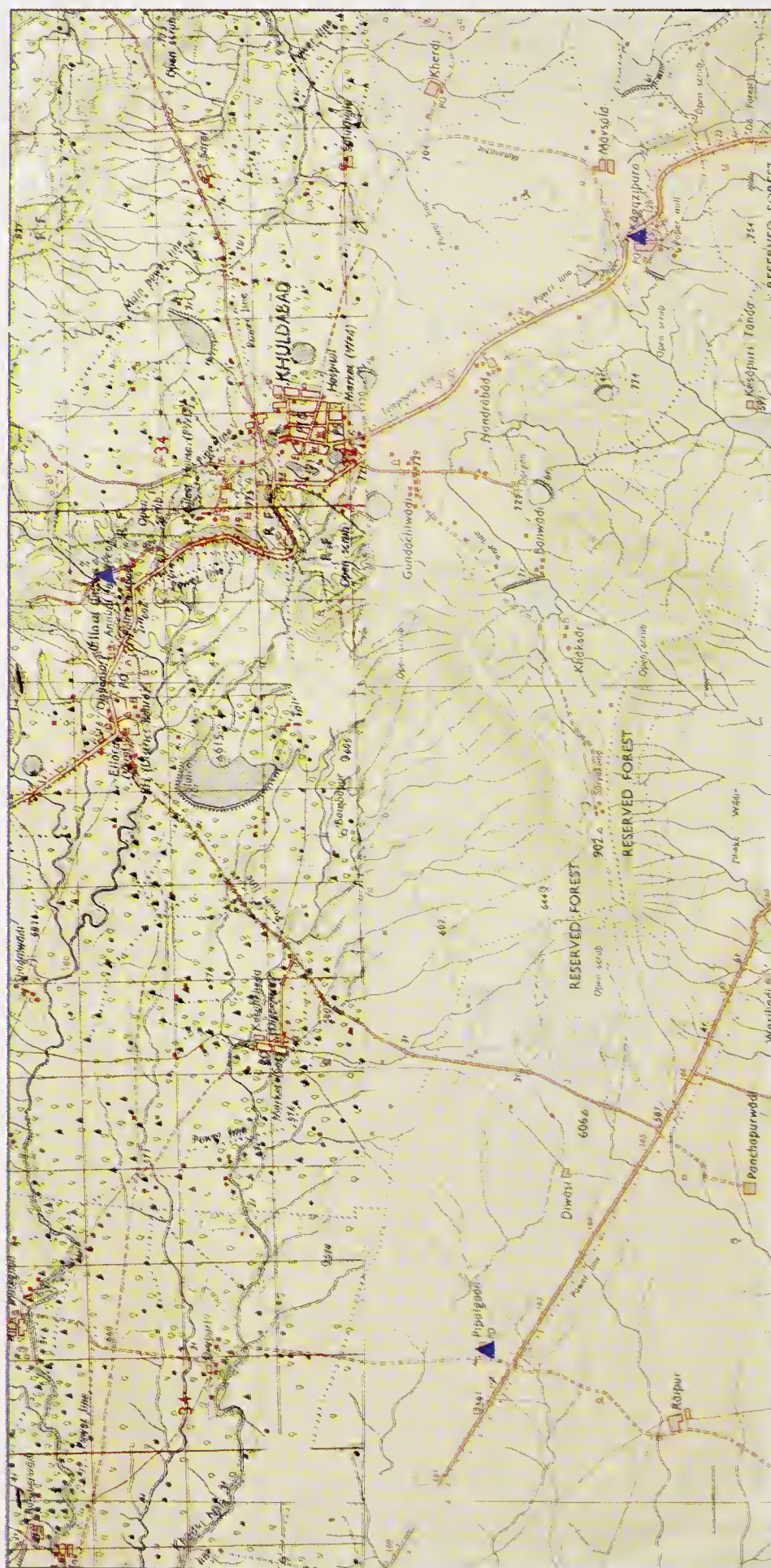
The area lies between E-W trending Tapi-Purna Fault in the north, NW-SE trending the Upper Godavari Fault in the south and the Kadam Lineament in the east.

The lineament fabric of the area is characterised by E-W and N-S to NNE-SSW trending linear dykes emplaced along pre-existing fractures. Occasional NE-SW trending micro lineaments (Plate IV-2) are also seen. A few ENE-WSW trending minor faults have been identified 50-60 km north of the area.

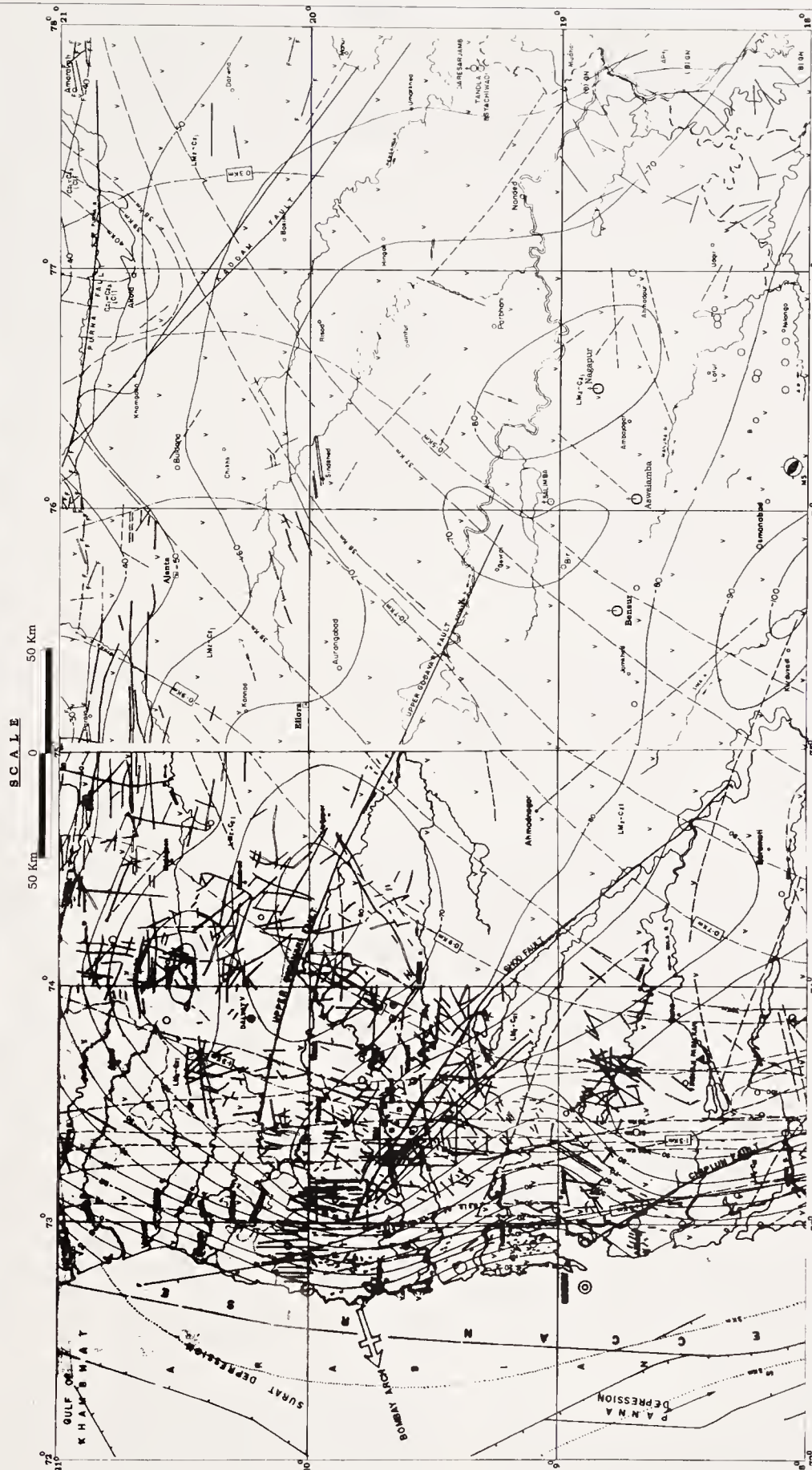
Towards north and northwest, the Dhule-Malegaon-Nasik-Dalvat area has been experiencing acoustic emissions and MEQ activity in recent years. Neotectonic activity is also inferred in the Girna river section in the Malegaon-Kalvan area, as indicated by rock-cut terraces (RCT), excessive pothole formation and microseismic activity.

Plate : V1-1

LOCATION MAP FOR MEQ STATIONS OF LOCAL MEQ NETWORK, ELLORA AREA,



SEISMOTECTONIC MAP OF AJANTA - ELLORA AND SURROUNDING AREA, MAHARASHTRA



LEGEND

	DYKES		FAULT		EPICENTRES OF EARTHQUAKE		LOCALES OF ACOUSTIC EMISSION		BOUGUER ORAVITY CONTOUR
	BASALT		LINEAMENT		FAULT PLANE SOLUTION		EXISTING SEISMIC NETWORK		DECCAN TRAP THICKNESS (Km)
	GNEISS								MOHO DEPTH (Km)

Geophysically the area is characterised by a gravity scene, where bouger anomaly contours value have NW-SE to ENE-WSW trends and their values range from -40 to -90 milli gal. Geophysical studies on the area reveal that the thickness of the Deccan trap cover is of the order of 800m. The area is characterised by Low/Medium heat flow.

2. Seismicity of the Area

The area falls in Zone-I of the Seismic Zonation Map of India (IS 1893: 1984 the code is under revision), which attributes that the zone is prone to earthquake upto magnitude of 6 with 20%

probability. The Maismal Plateau area bounded by latitude 19° - 21° N and longitude 74° - 76° E has registered a series of earthquakes between 1858 and 1993 (Table VI-1). These are mainly low to moderate shocks of magnitude < 4.3. The Killari earthquake of 30th September 1993 had a magnitude of 6.3 and is located about 200 km south of the cave area. During this earthquake Maismal Plateau has recorded intensity of less than V on MSK scale. Micro seismic activity accompanied with acoustic emission has been observed in Gevrai in the south and in Dalwat coordinate towards west, which is approximately 100-120km away from the heritage sites.

Table VI-1

LIST OF PROMINENT EARTHQUAKES IN THE NEIGHBORHOOD OF ELLORA CAVES (Lat. 19°-21°N; Long. 74°-76°E)

Sl. No.	Year	Month	Day	Lat° N	Log°E	M	Loc	Source	Status
1.	1858	12	31	21.000	75.000	4.3 Ms	Khandwa	CGS	Historical
2.	1862	11	18	20.900	74.800	3.7 Ms	Khandwa	GOM	Historical
3.	1869	7	04	20.900	74.200	4.3 Ms	Nasik	CGS	Historical
4.	1869	7	12	20.900	74.800	4.3 Ms	Dhulia	CGS	Historical
5.	1953	—	—	19.000	75.800	3.7 Ms	W-Mah	GOM	Recorded
6.	1957	09	25	20.800	74.200	4.2 Ms	W. Dhulia	CGS	Recorded
7.	1980	01	08	20.900	75.100	3.5 Ms	Dhulia	GOM	Recorded
8.	1980	02	01	21.000	74.200	3.1 Ms	Nasik	GOM	Recorded
9.	1980	05	01	21.000	76.000	4.1 Ms	Nasik	GOM	Recorded
10.	1992	10	29	—	—	4.7Ms	Latur	IMD	Recorded
11.	1993	09	30	18.07	76.62	6.3Mb	Latur	IMD	Recorded

3. Seismic Rigidity

From the seismic hazard perspective, the area can be divided into two prominent seismic rigidity zones having different morphological setup and

geotechnical characteristics. The Seismic Rigidity (SR) factor of the two basic categories of ground, namely alluvium /soil and basalt found in the area is given below in table VI-2

Table VI-2

SEISMIC PARAMETERS FOR THE FORMATIONS

Zone	Lithology	P- wave velocity Vo km/sec	Density σ gm/cc	Intensity increment factor	Seismic Rigidity SR ($V_o \times \sigma$)
I	Alluvium/Soil	1.8	1.9-2.8	1.7-2.8	3.42-5.04
II	Deccan Basalt	4.5-4.8	2.9-3.0	0	13.05-14.4

(Velocity data from Project CRUMANSONATA, Rao, K.V. etal. GSI Publication, 1995)

Zone I: Consists of recent alluvial fill and thin soil cover, with low slopes of 2- 5° and having shear wave velocity (V_s) of ≤ 1 km/sec with Seismic Rigidity (SR) ranging from 3.4 - 5.04.

Zone II: Consists of amygdular (and vesicular) and dense basalt, with V_s 2.6 -2.8 km sec. The slope is of the order of >40 % with Seismic Rigidity (SR) ranging from 13.05 - 14.40.

All the caves fall in Zone II, which are characterised by high seismic rigidity. The caves have been carved in basaltic lava flows of Deccan trap, overlain by soil and alluvium. Soils vary in thickness from a few centimeters upto 2m., whereas thickness of alluvium is upto 15 m. Lithological attributes of the cave domain are described in Chapter IV.

MICRO EARTHQUAKE (MEQ) STUDIES

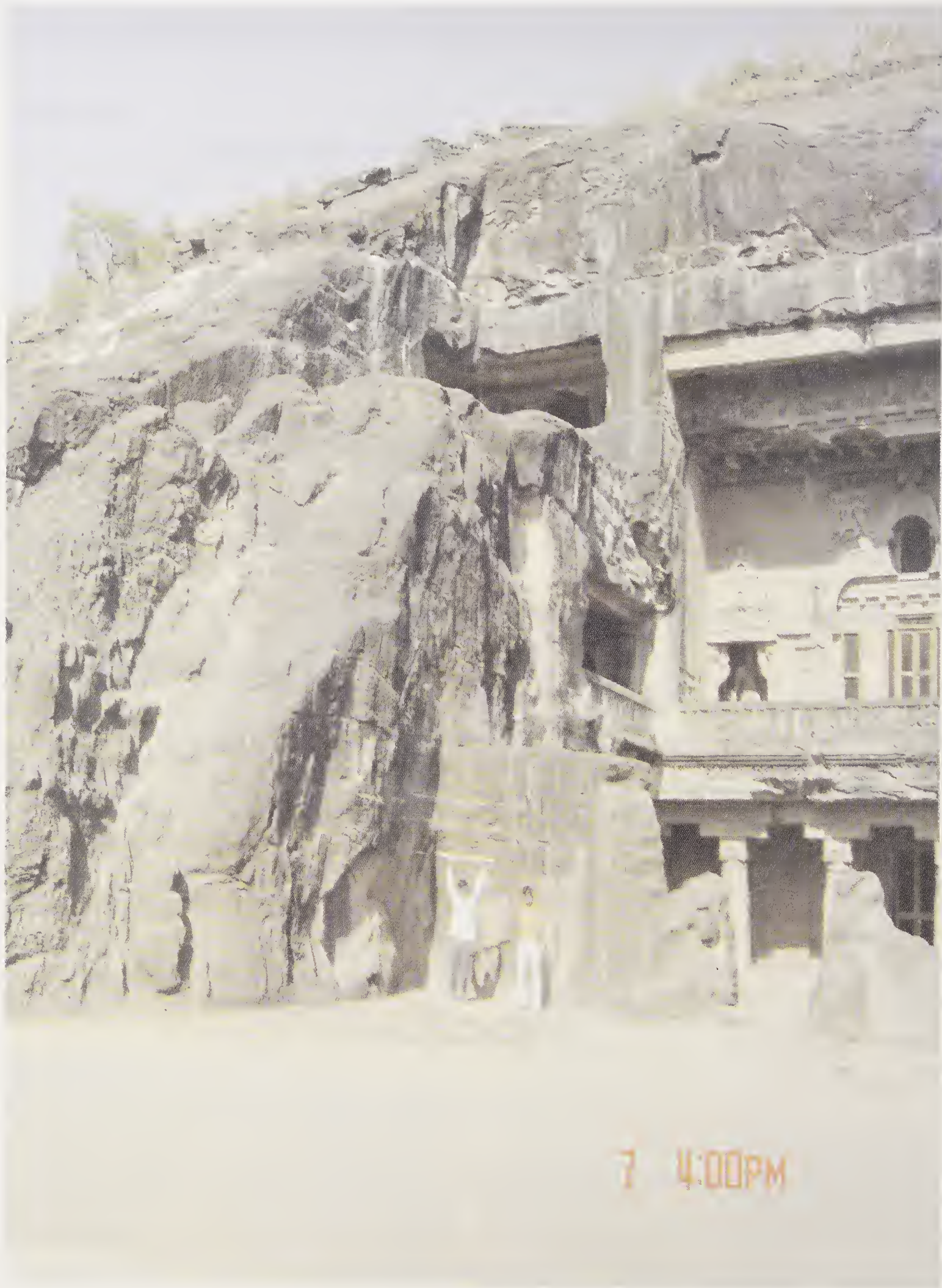
Seismic observatories are located at Nasik and at Akola. From these observatories it is not possible to detect low magnitude and shallow to very shallow seismic activity, if any, in the area. Micro earthquakes have similar source mechanisms as strong earthquakes but occur more frequently and yield information about source of seismicity. As per Gutenberg-Richter relationship, frequency of occurrence of earthquakes increases by factor of

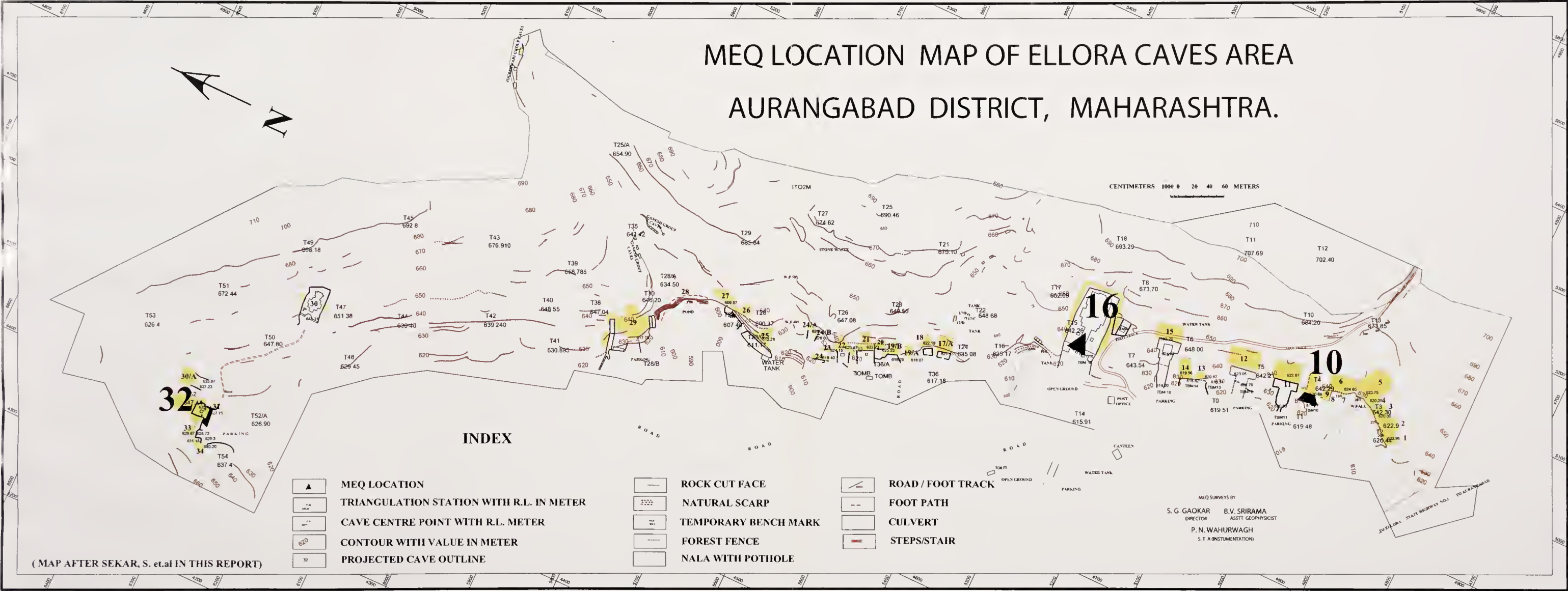
about 10 with decrease in the magnitude by one. So, large amount of data can be collected in a short period of time employing MEQ surveys. As a result, micro earthquake monitoring offers ideal method for determination of seismological status of any given area. On these considerations, the seismic activity monitoring in Ellora area was carried out for a period of one week. Initially the aperture radius for the network was kept at 500 m and later extended to 5 km.

INSTRUMENTATION AND LAYOUT

The MEQ seismometers SS-1 along with the analog PS-2 Recorders (Kinematrics, USA) were used for conducting seismic monitoring in Ellora area. The seismometer output is conditioned through amplifiers and filters and finally fed to motor driven stylus for etching on the smoked paper. The final record in the form of seismogram is fixed on the smoked recording paper using mixture of thinner and lacquer.

MEQ sensors along with recorders were established at Ellora inside caves 10, 16 and 32 with network aperture radius of about 500 m for monitoring seismic activity, as well as recording events from distant sources (Plate VI-3). Subsequently, the MEQ stations were established at Ellora cave 32 (20° 1' 30 " N: 75° 10' 39" E, 46P/4), Kagazpura





(19° 58' 22" N: 75° 12' 48" E, 47M/1) and Pimpalgaon (19° 59' 16" N: 75° 5' 57" E, 47M/1) for setting up larger network with aperture radius of about 5 km (Plate VI-1). Phase data was

read from the seismograms and magnitude of ground vibrations was calculated from the trace amplitudes of waveforms

Table VI-3

DETAILS OF THE EVENTS RECORDED IN ELLORA AREA

Sl. No.	Date	Hr	Min	Sec	S-P (sec)	Trace AMP (mm)	Freq (Hz)	Coda (sec)	VIB AMP/ Ground Motion (nm)	MAG (md)	Distance to Source (km)	Remarks
1	15/9/99	4	2	15.5	24	9.5	1	50	70	2.6	192	Local Event
2	15/9/99	8	54	39.5		38	1.25	310	226	*3.1	--	Regional/ Teleseismic

*Uncorrected for distance to source

MEQ EVENTS

Two seismic events were recorded on seismograms in Ellora area, Aurangabad district, Maharashtra, during the period from 13-9-99 to 15-9-99 and 22-9-99 to 25-9-99. The phase information and other seismic parameters for the events are as shown in Table VI-3 above

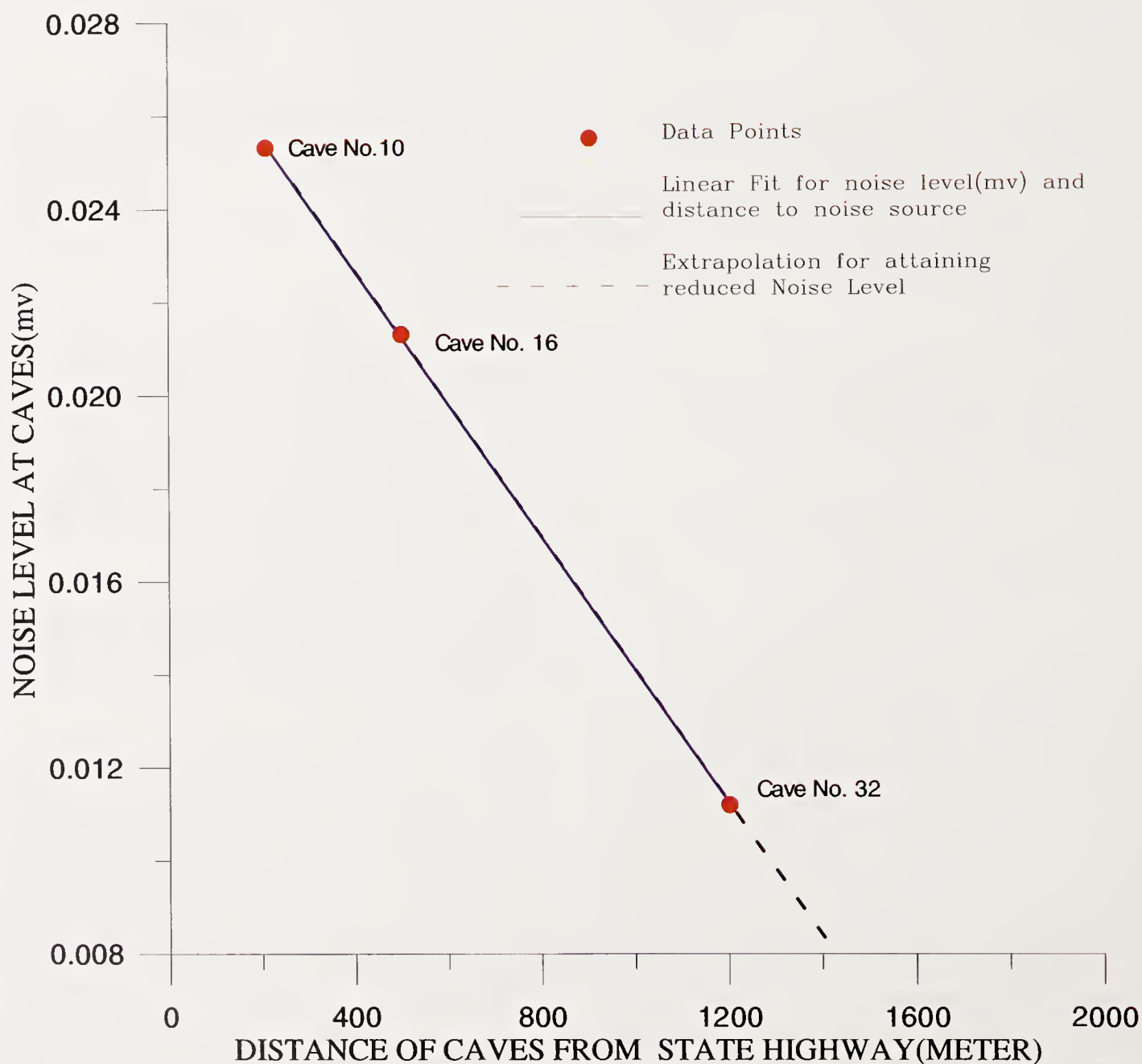
Both these events were recorded on 15-9-99. One of these events is of local range with approximate epicentral distance of 192 km, with Coda magnitude of 2.6md. Vibration amplitude of 70 nm was recorded for ground movement due to this event. Other event is from regional/ teleseismic distance with magnitude 3.1md and produced vibration amplitude of 226 nm around caves. Incidence of these events was also confirmed from digital record of BBS observatory, Jabalpur. The ground vibrations were of small amplitude due to large distances from the sources. Due to low accelerations as well as short duration, these events are not of significance as far as damage to the monuments is concerned.

From the short period monitoring it is inferred that events of magnitude greater than 0.5 are absent within an area of 100 km radius around Ellora caves. The vibration effect due to the events recorded is not important as far as damage to the monuments is concerned.

SEISMOTECTONIC EVALUATION AND HAZARD POTENTIAL (DETERMINISTIC APPROACH)

From a seismotectonic point of view, the area in the west, south and north of Ellora have significance. In the south, the area is traversed by the Upper Godavari fault, which is a deep fundamental fault. The fault cuts across the basaltic lava flows and is characterized by neotectonic movement, as indicated by anomalous behavior of the river, raised alluvial terraces and thick pile of alluvium in its upper reaches. Significant seismic activity has been observed at the northwestern and southern tips of this fault. The epicenter of Killari

GRAPH SHOWING DEPENDENCE OF NOISE LEVEL
ON DISTANCE OF CAVES FROM STATE HIGHWAY
ELLORA AREA, AURANGABAD DISTRICT, MAHARASHTRA



earthquake of 30th September, 1993 (M6.3), the earthquake in the same area of 29th October, 1992 (M 4.7) and Acoustic Emissions (AE) related to microearthquake activity reported from Gevrai, Salimba, Aswalambe-Nagapur, Ambajogai and Kaij fall in this fault zone.

Towards north and northwest, the Dhule-Malegaon-Nasik-Dalvat area has been experiencing significant microseismic activity in the recent years. Neotectonic activity is also inferred in the Girna river section in the Malegaon - Kalvan area, as indicated by rock-cut terraces (RCT), excessive pothole formation and microseismic activity.

Though Ellora area proper does not show any major seismic activity, the seismic status of the area assumes significance due to seismogenic potential of the area to its north and south. In the event of the maximum credible earthquake of magnitude 6, around an epicentral distance of 50 km, the expected peak ground acceleration (PGA) is 56 cm/sec². This calculation has been arrived at using the formula $\log A = 0.336M - 0.728 \log R + 0.969$ where R is epicentral distance and M is the magnitude. A magnitude of 6 has been taken with reference to the probability of a seismic event occurring in Zone-I.

Table VI-4

**PENALTY FACTORS FOR DIFFERENT FORMATIONS
AND LITHOLOGICAL PARAMETERS**

Lithological Parameter	Rock	Alluvium/Soil
Depth (m)	>25m	0-2m
	Vs 2.6-2.8 km/sec	Vs 1 km/sec
	P 0 - 0.50	P 1-3
Depth to water table	d>10m - P 0	d<10m - P 0.5-3
Distance from major discontinuity	d 100m P 0	-
Overall morphology	Ridge P 1-3	Flat P 0.2
Landslide prone	Quiescent? P 2-6	Stable P 0
Cliff edge distance	d<10m d >10m	P 6 - P 0
Cavity	P 0-3 Absent to underlying	-

Keeping seismotectonic perspective in view as above, a broad assessment of seismic exposure of the area is attempted. The table VI-4 shows an estimate of seismic exposure of the area and also assigns different weightage and penalty (P) [empirically assessed] to the various parameters (as listed). The weighted sum gives an indication

of vulnerability index. From the available data, on thickness of lithological layers, water table level, local and overall morphology, distance from active faults, slope stability, exposure to rock falls, slides etc. the penalty status has been worked out. The value of penalty status for different segments of cave domain vis-à-vis the vulnerability varies from



0 to 6. By combining all seismological and geological information, the area has been characterized as low to moderately vulnerable to seismic activity. However, keeping the potential seismogenic zones towards the north and south of the area and the trends of Stable Continental Region (SCR) earthquake striking hitherto unknown areas, a systematic monitoring of earthquake activity by seismic network is essential. The MEQ monitoring has been attempted, during present studies, only for short duration employing Analogue MEQ. Looking to the importance of this world heritage monument, it is suggested to conduct long duration studies deploying digital MEQ instruments. A specific study should be conducted for Kailash Temple and other vulnerable caves, deploying digital equipments to assess site response characteristics. A permanent monitoring system for the cave domain, especially Kailash Temple should be considered.

CONCLUSIONS

Two events, one of them local with an epicentral distance of about 192 km from Ellora Caves with magnitude of 2.6 and the other event of teleseismic origin with magnitude 3.1 were picked up during weeklong MEQ monitoring in the Ellora area. These events produced vibration amplitude of 70 nm and 226 nm respectively, at Ellora caves.

Systematic monitoring of seismic activity may be taken up by establishing permanent Digital MEQ/Broad Band Seismograph observatory in the area.

SURFACE NOISE SURVEY

The generation of noise due to vehicular traffic and tourist inflow lately increased manifold, in

and around Ellora caves area. The State Highway passing through the neighbourhood of these caves is the major contributor of surface noise generated in the area. Long periods of exposure to the vibrations induced by human activities may have a deteriorating effect on the caves, sculptures and paintings even if these are low magnitude. Study of relative noise levels, too feeble to be perceptible by human beings, can be detected and studied by MEQ recorders due to their high magnification capabilities. MEQ instrument (analog) consisting of SS-1 seismometer and PS-2 recorder of Kinematics, USA, were deployed for noise studies.

METHODOLOGY

Ground motion picked up by the seismometer, is fed to the amplifier in the form of voltage output and filtered to select particular frequency band. The amplified and filtered output is given to the pen motor, which etches the trace of the waveform on smoked paper, fitted on the rotating drum. The record is fixed using mixture of thinner and lacquer. The instrument gains are adjustable from 0 to 72 dB. For maximum sensitivity, the gains were kept at 66 dB to 72 dB for recording vibrations generated by vehicular traffic and tourist inflow and movement. The measurements of less than 20Hz frequency were recorded. Bandwidth of the measurement was controlled with low pass filter setting. Recorder speeds were set at 120mm/minute to 240mm/minute for high resolution.

LAYOUT FOR NOISE SURVEY

Ellora caves are located at the western margin of a N-S trending hill range near Ellora village. The State Highway linking Aurangabad and Dhule passes through the close vicinity of the caves. The



MEQ recorders were placed in the cave 10, 16 and 32, located at distances of about 210 m, 500m and 1200m respectively, from the state highway. In cave 10 the sensors were placed on the raised portions of the floor in the SW corner of the interior of the cave and subsequently shifted in the gallery. In cave 16 the sensors were kept over the raised platforms onto the left, immediately near the entrance of the cave through the gate at the northwestern part. In cave 32 the sensors were placed on the raised platform near wall at the SE corner inside the cave.

RESULTS AND DISCUSSIONS

The seismometer responds to different frequencies to different extents, which is known as frequency response of the seismometer. However, this factor was identical for all caves and the relative changes in the maximum amplitudes in particular frequency range reflect the effect of noise sources at each of these locations. Response depends upon the distance of recorders from the noise sources. Since the site response factors (which depend upon the bedrock characteristics) vary from cave to cave, the relative noise level reflects the proximity to the noise source. Noise levels observed in the frequency band of 8 to 20Hz, due to high frequency noise generated by artificial sources (vehicular traffic),

are important for present surveys. The absolute values observed are of low order in this frequency range. These are important only if the exposure is over very large span of time. Maximum noise level was observed in cave 10, which is nearest to the highway (210m) and about 300m from the parking lot (Table-VI- 5). The relative decrease in the maximum noise level from cave 10 to cave 32 in the frequency range of 5 to 15 Hz is explained in terms of increase in distance of these caves from the highway.

When plotted as a function of distance, the noise levels are inversely proportional to the distance from highway. Beyond a distance of 1500m these are reduced to very low levels (Plate VI-4). Ground vibration generated near the caves due to movement of tourists beyond 15m was not important, since, sharp spikes with frequency of around 12Hz recorded die down sharply. Consequently this noise is not important unless a very large number of tourists are present inside the cave. The tourists should be encouraged to proceed slowly and observe silence within the cave premises. Light vehicles approaching or leaving the parking area; contribute to some noise at cave 16. However this noise is not present continuously. Assuming linear attenuation of this noise level with distance, shifting of parking place to distance

Table VI-5

NOISE LEVEL RECORDS AT ELLORA CAVES

CaveNo.	Maximum Noise Level Centered	Distance From State Highway	Distance from parking at Ellora near Cave No. 16
10	0.0253 mV	210m	300m
16	0.0213 mV	500m	150m
32	0.0112 mV	1200m	900m



beyond 500m will help in reducing the noise level by 50% of the present level

CONCLUSIONS

High noise levels were recorded at cave 10 (both during day and night) as compared to those at cave 32. The main noise source was identified as the heavy vehicular traffic on state highway passing through the vicinity of caves. Study of attenuation of the noise with increasing distance from the caves indicate that relocation of the highway to a distance beyond 1.5 km will effectively reduce

the ground noise to a sufficiently low level. The proposed diversion of the highway from Palaswadi via Kasabkheda may be considered to reduce the noise level at Ellora caves.

RECOMMENDATIONS

The tourist vehicles approaching and leaving the parking lot near cave 16 were also found to generate higher noise levels at cave 16. Hence the present parking area may be shifted to a safer distance of about 500m away from the present one to reduce noise level by 50%.

C H A P T E R V I I

GEOTECHNICAL STUDIES OF ELLORA CAVES AREA

MORPHOMETRIC STUDIES

By

G. GONNADE, Geologist (Sr.)

GEOTECHNICAL INVESTIGATION OF SLOPES

By

MOHD. J. AHMED, Geologist (Sr.)

GEOTECHNICAL INVESTIGATION OF CAVES 1-16

By

Dr. C. JOSHI, Geologist (Jr.)

GEOTECHNICAL INVESTIGATION OF CAVES 17-34

BY

M. M. POWAR, Geologist (Sr.)

SURFACE WATER MANAGEMENT

By

S. SEKAR, Geologist (Jr.)



CHAPTER-VII

GEOTECHNICAL STUDIES

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VII. GEOTECHNICAL STUDIES

Geotechnical studies were carried out with a view to identify the problem areas (seepage zones, unstable slopes, potential zones of de-slabbing, rock fall, toppling etc.), to identify the causative factors (weathering, process of valley widening) and to suggest selective protection / treatment measures. The remedial measures suggested at Ellora involve mainly civil engineering works. The suggested measures include plain and reinforced shotcreting, with or without chain link and wire mesh of varying thickness from 25 – 100 mm thickness; rock bolting/ anchoring (2m to 8m) with grouting and tensioning; construction of drains at various levels; training of nalas by regulation of gradient.

Geotechnical investigations were carried out inside the caves to study the details of joints and fracture zones on the crown of the cave, micro and macro scale features that may have possible bearing on the stability of caves, infiltration and seepage zones.

Slope stability problems at Ellora are confined to the cave portals and the adjacent inter-cave slopes. The slopes immediately behind the caves are flatter, gentler and stable. Deep semi circular scarps, 20 to 37 m in height have been formed by water action in nalas near caves 5, 17, 24 & 29. The outer portions of caves 1-9 have perished, creating an overhanging block from which certain parts have been dislodged. Overhangs created by excavation of caves have also become vulnerable at a few places especially in cave 16. Other than this, certain blocks have collapsed due to separation along unit contacts. Stability problems, which are

in general restricted to the outer 1-4 m in most caves are due to jointed and fractured blocks. The cave interiors are relatively stable. The presence of four sets of joints, three vertical and a steeply dipping fourth set of relief joints along with the fracture zone and cooling cracks, has accentuated weathering and rendered the cave facades and certain slope segments weak. Wherever the fracture zone has intersected the cave openings outer portions of the caves have collapsed as seen in caves 1-4, 13 & 14. The relief joints with progressive undercutting of toe have played a major role in the retreat of the slope by about 5m.

The natural processes of weathering along with scarp retreat and biotic interference have had a deleterious impact on the sculptures and paintings in the caves and its environs. Unstable slopes and seepage are the two major causes of concern.

MORPHOMETRIC STUDIES

Slope map for about 0.15 sq. km area has been prepared (Plate VII - 1) based on the topographic map. Seven categories of slopes have been identified and demarcated.

Category – I Slopes include those slopes that are approximately more than 70° and are represented by scarps, over hangs and negative slopes. These slopes are the most vulnerable slopes that lead to block detachments in the area.

Category – II Slopes have angle of >45° but less than 70°. These slopes generally have steep angle valley relief joints/fractures that lead to block detachment and formation of scraps.



SLOPE MAP OF ELLORA CAVES AREA, AURANGABAD DISTRICT, MAHARASHTRA.

INDEX

SLOPE ANGLE	CHARACTERISTIC SLOPE
>70°	SCARPOVERHANGS
>45°	PRECIPITOUS SLOPE
30° TO 45°	VERY STEEP SLOPE
18° TO 30°	STEEP SLOPE

SLOPE ANGLE	CHARACTERISTIC SLOPE
10° TO 18°	MODERATELY STEEP
5° TO 10°	MODERATE SLOPE
<5°	GENTLE LEVEL SLOPE
-	CAVE STRUCTURE

	TRIANGULATION STATION WITH R.L. IN METER
	CAVE CENTRE POINT WITH R.L. IN METRE
	CONTOUR WITH VALUE IN METRE
	PROJECTED CAVE OUTLINE
	NALA WITH POTHOLE
	NATURAL SCARP

	ROCK CUT FACE
	DRAIN CHANNEL
	RETAINING WALL
	TEMPORARY BENCH MARK
	FOREST FENCE
	POWER LINE

	ROAD/FOOT TRACK
	FOOT PATH
	CULVERT
	BUILDING
	STEPS/STAIR
	PIPE LINE

G.GONNADE
GEOLOGIST(Sr)

PREPARED BY:
PREM BABU
GEOLOGIST(Jr)

Category –III Slopes are formed as very steep slopes having slope angle between 30° and 45°. These slopes are not vulnerable until they are disturbed and have their scree/transported soil cover supporting grassy vegetation.

Category – IV Slopes include those slopes that have angles between 18° & 30°.

Category – V Slopes have angle between 10° and 18°. These areas are stable and do not pose any problem of instability and have thin scree and soil cover.

Category - VI Slopes are moderate slopes having slope angle between 5° and 10°. These slopes are present in the riverbank and at the T-1 terraces. Such slopes supporting good vegetation are mostly used for developmental works.

Category - VII Slopes are the gentle to level slope having slope angle less than 5°. The pathways fall in this category and are seen on terrace T1 and T0 surface.

Slopes falling in categories I to IV need strengthening for stabilization. Slopes of category V to VI, whenever required should be used for plantation.

GEOTECHNICAL

INVESTIGATION OF SLOPES

Studies were conducted to assess the stability of the slopes immediately above the caves and in the

adjacent inter-cave zones. Geotechnical mapping was done to assess the geotechnical parameters and evaluate the basis for suggesting remedial measures. The Geotechnical map shown in plate VII – 2, depicts the nature of overburden, the litho-units, geomorphic and physiographic features and other details of survey etc. Terrestrial stereo-photographic methods have been used to prepare rock mass distribution & slope protection maps. Characterization of rock mass was carried out on the basis of three basic parameters of relative strength, joint volume and relative weathering. Rock mass distribution maps were then prepared based on rock mass characterization and joint analysis. Analysis of rock mass distribution maps was done to determine selective protection/treatment measures. The slope protection maps show locations of areas requiring specific protection measures. The identified slope protection measures have also been marked on photographs.

SLOPE CHARACTERISATION

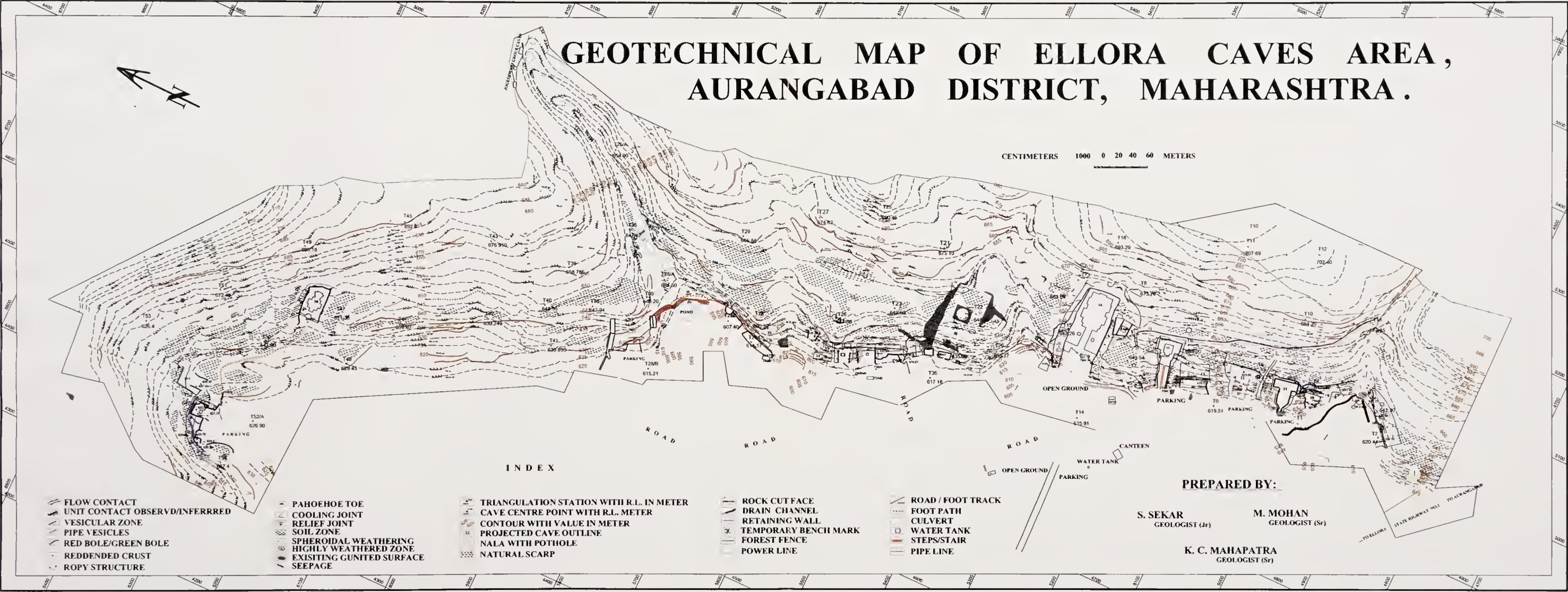
As a part of the Geotechnical studies the slopes around the caves were studied and assessed for stability. Slope protection maps were prepared based on the rock mass distribution, identifying areas requiring site-specific measures for treatment. The cave area at Ellora has been divided into four sectors (Table-VII) and slope protection maps of all these sectors have been prepared.

Table VII-1

DETAILS OF SECTORS

SECTOR	CAVES	SECTOR DIRECTION
I	1-7	NE – SW
II	8 -16	NNW – SSE
III	17-30	NNW – SSE
IV	31 –34	NE – SW





The slope within the cave confines have been divided into:

#1	<u>Lower slope (with caves)</u> : Marked by steeper gradients and scarps at several places.	RELATIVELY UNSTABLE
#2	<u>Upper slope</u> : marked by gentler gradient with step like scarps	RELATIVELY STABLE

ROCK MASS CHARACTERISATION

Terrestrial stereo photographic methods have been put to use for preparing the slope maps / rock mass distribution maps. Based on three basic parameters of rock strength, joint volume/ degree of jointing

and degree of weathering the exposed rock on the cut slope surface was zoned into different rock mass categories and depicted on rock mass distribution maps. The categories of rock mass are shown in Table -VII-2.

Table VII-2

ROCK MASS CATEGORIES

STRENGTH	JOINTING	WEATHERING	ROCK MASS CATEGORY
High Strength (H)	Widely Jointed (w)	Slightly Weathered Rock Mass (s)	Hws
High Strength (H)	Moderately Jointed (m)	Slightly Weathered Rock Mass (s)	Hms
High Strength (H)	Widely Jointed (w)	Un- Weathered/ Fresh Rock Mass (u)	Hwu
High Strength (H)	Closely Jointed (c)	Slightly Weathered Rock Mass (s)	Hcs
Moderate Strength (M)	Moderately Jointed (m)	Slightly Weathered Rock Mass (s)	Mms
Moderate Strength (M)	Closely Jointed (c)	Slightly Weathered Rock Mass (s)	Mcs
Low Strength (L)	Closely Jointed (c)	Moderately Weathered Rock Mass (m)	Lcm

JOINT ANALYSIS

The joint data analysis and characterization of slope surfaces for evaluating the slope treatment/

protection measures has been done for each sector. Four sets of joints were identified and characterized in the area (Table VII-3).

Table VII-3

JOINT SETS EXPOSED IN THE AREA

JOINTS	TYPE	PERSISTENCE	APERTURE
J ₁	Basal set with rolling dips of 2-4°	Persistence > 10 m	Mostly weathered, clay filled to tight
J ₂	NE – SW / Vertical	Persistence < 10 m	Clean, tight
J ₃	WNW – ESE /Vertical	Persistence < 10 m	Clean, tight to gapping
J ₄	Relief joints / 55 - 60/SW	Persistence < 10 m, discontinuous.	Gapping showing dilation, clay filled,



Besides the above, a number of random cooling cracks are noticed in the area. A westerly dipping highly fractured zone exists in front and top of all caves from cave 1 to cave 34. Wherever this fracture zone has intersected the cave openings, the frontal portions of the cave have collapsed as seen in caves 1- 5. The presence of four sets of joints along with cooling cracks and fracture zone have accentuated weathering and rendered the cave frontals and certain inter cave areas weak. The relief joints (J_4) with progressive under cutting of toe have played a major role in the retreat of the slope face by about 5 m by progressive collapsing. The seepage in most of the caves is confined to the affected zone of relief.

The dense basalt with prominent basal set of joints (J_1) and unit/ flow contacts at the roof portion of the caves has caused local gravity falls as in caves 10,16 and 18.

The differential weathering along the fracture zone and unit contacts has created negative slopes / overhangs in the rock mass as seen in valley sections near caves 5, 13, 16, 28 and 29.

The weathering grades used are based on International Association of Engineering Geology IAEG (1982), ISRH (1974) & GSI (1970). In this classification Grade I represents fresh unweathered rock. Grade VI, on the other hand represents residual rock. The following is the description of the various grades (Table VII-4).

Table VII-4

WEATHERING GRADES

GRADE	CLASSIFICATION	DESCRIPTION
I	Unweathered/Fresh Rock	No visible signs of weathering. Rock fresh and crystals bright. New discontinuities may show slight weathering.
II	Slightly Weathered Rock	Penetrative weathering developed on open discontinuity surfaces but only slight weathering of rock material. Discontinuities are discolored and discoloration can extend into rock up to a few mm from discontinuity surfaces.
III	Moderately Weathered Rock	Slight discoloration extends through the greater part of the rock mass. The rock material is not friable except in the case of poorly cemented sedimentary rocks. Discontinuities are stained and/or contain a filling comprising altered materials.
IV	Highly Weathered Rock	Weathering extends throughout rock mass and the rock material is partly friable. Rock has no luster. All material except quartz is discolored. Rock can be excavated with geologists pick.
V	Completely/Extremely Weathered Rock	Rock is totally discolored and decomposed and in a friable condition with only fragments of the rock structure and texture preserved. The external appearance is that of a soil.
VI	Residual Rock	Soil material with complete disintegration of texture, structure and mineralogy of the parent rock.



ASSESSMENT OF SLOPE STABILITY

The following is a sector wise assessment of slope stability.

SECTOR I: (CAVES – 1 – 7): Sector aligned NE – SW.

The rock mass is of 'Mms' type with local 'Lcm' patches in the flow contact zones.

The vertical joints set (J_2 & J_3) and the fracture zone in combination with the J_1 have rendered the frontals of cave 1 to 5 unstable and accentuated seepage in the outer 1 – 2 m zone of caves 1, 2 & 4. No seepage is seen in caves 5, 6 & 7. The facades of most of these caves have collapsed. Relief joints/cracks in the outer 5 m zone cause seepage inside the caves. The nala above cave 5 with large potholes does not contribute to seepage in the caves but needs attention to prevent the possibility in the long run.

The differential weathering along certain units/unit contacts have created overhangs in the back slope of cave 5. This sector is considered to be most potential from the slope stability point of view.

The rock mass distribution map of sector I is presented in plate VII - 3

SECTOR II: (CAVES: 8 – 16): Sector aligned NNW – SSE.

The rock mass is mostly of *Mms* type with *Lcm* type in the unit contact zone.

The presence of relief joints (J_4) along with cooling cracks has accentuated weathering of slopes. The seepage in the cave is confined to the outer 1-2 m zone of relief joints. The dense basalt with predominant basal set (J_1) and the flow contacts at the roof level of caves – 10, 16 (side caves) have caused local gravity falls.

Differential weathering along fracture zone & unit contacts have created overhangs in the rock mass as in caves 13, 16. The rock mass distribution maps of sector II is presented in plates VII – 4, VII – 5, VII – 6, VII – 7 & VII – 8.

SECTOR III: (CAVE 17-30): Sector aligned NNW-SSE.

The rock mass in general is 'Mms' and 'Mcs' type with patches of 'Lcm'. The weathering (Grade III/II) is very pronounced in the caves and outer slopes.

The vertical sets of joints (J_2 & J_3) in combination with the basal set (J_1) have caused wedge failures in the frontals of cave 17, 18 & 21.

Prolonged erosion along the unit contact has resulted in negative/reverse slopes (cave: 19, 20, 21, 25, 26, 28) that have made the cave frontal slopes critical with overhangs. Accentuated seepage is seen in the outer relief zone of cave 17.

Presence of flow contacts at the roof have resulted in gravity falls from the roof (cave- 17-19) and reduced the cover over the roof.

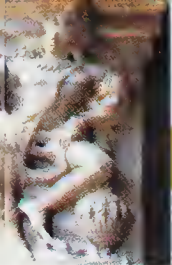
The rock mass distribution map of part of sector III is presented in plates VII – 9.

SECTOR IV: (CAVE- 31- 34): Sector aligned NE-SW

The rock mass in general is of 'Mms' and 'Mcs' type with a few patches of 'Lcm'.

The relief joints (J_4) with dips of 50-65° towards SW in the outer zone of 2-5 m. have made the slopes critical at certain locations. Seepage in the outer zone of 2-3 m with relief joints is very pronounced.

The weathering (Grade III & II) is very pronounced in the cave surroundings.



PROPOSED SLOPE PROTECTION AND TREATMENT MEASURES

Slope protection maps based on the rock mass distribution were prepared, identifying areas requiring specific treatment with means like shotcrete (25-50 mm.), reinforced shotcrete, with wire mesh (100 mm thickness), rock bolts and anchors (20-25 mm diameter; grouted, tensioned). The treatment measures need to be integrated during execution, with other remedial measures to improve the cave stability, stop seepage and for effective surface water management. Some finer details of the remedial measures are to be worked out at the time of execution.

Slope protection maps have been prepared separately for each sector. The slope treatment map for sector I is presented in plate VII-10. The slope treatment map for sector II is presented in plates VII-11, VII-12, VII-13, VII-14 & VII-15.

The slope treatment map for sector III is presented in plates, VII-16 VII-17 & VII-18.

For greater appreciation of the nature and type of treatment measures suggested, these have been marked on actual site photographs and presented in plates; Caves 1 to 4 in Plate VII-19; caves 5 to 7 in Plate VII-20; cave 10 in Plate VII-21; cave 11 in Plate VII-22; cave 12 in Plate VII-23; caves 13 & 14 in Plate VII-24; cave 15 in Plate VII-25; cave 16 in Plates VII-26, 27, 28, 29, 30, 31, 32, 33, 34, 35, 36 & 37; cave 17 in Plate VII-38; caves 19 to 21 in Plate VII-39; caves 25 to 27 in Plate VII-40; cave 29 in Plate VII-41; cave 32 in Plates VII-42 & 43 and cave 33 in Plate VII-44.

The broad protection measures for slopes in each sector are given in Table-VII-5 and a quantitative estimation of treatment measures are given in Table - VII-6.

Table VII-5

DAMAGE ASSESSMENT AND SUGGESTED SLOPE PROTECTION /TREATMENT MEASURES

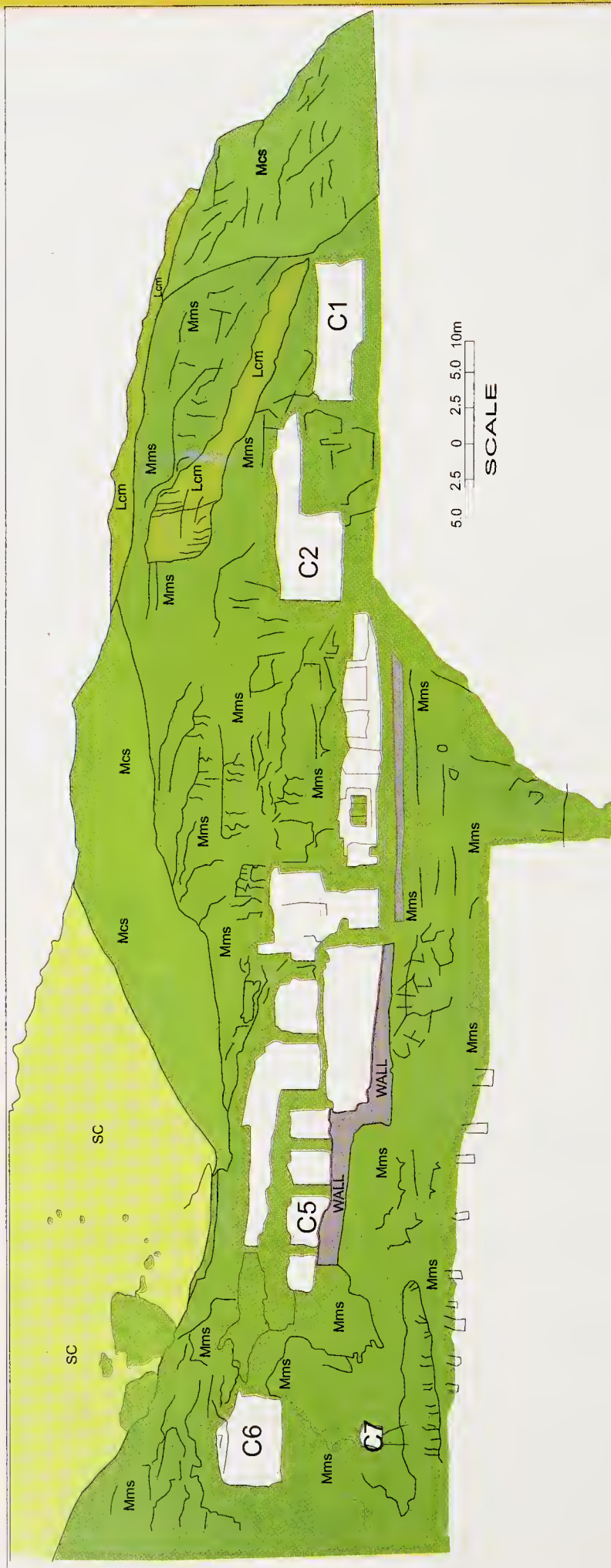
SEC TOR	DAMAGES ASSESSMENT	SLOPE PROTECTION / TREATMENT MEASURES
I	Unstable cave frontal.	Reinforced shotcrete with systematic bolting (length of 2-8m), Bolts to be tensioned, grouted.
	Seepage in the outer portion of caves along the relief zone of 2-5 m.	Stripping of soil cover in a width of 15 m from the edge or up to the existing longitudinal drain and treat it with shotcrete and followed by relaying of soil.
	Differential weathering along unit contacts creating reverse slopes with over hangs.	Stone packing along the eroded unit contacts and treating with reinforced shotcrete with provision of drainage holes.
	Unstable wall portion due to a crack almost parallel to the relief joint set (J_4) dipping by	Construction of a toe wall and/or treating with tensioned cables/rock bolts. Consultation

	50-55°/SW (Cave 6 & 7).	with architectural and structural civil engineer required.
II	Pronounced weathering along the zone of relief in outer 5 m.	Shotcrete (25-50 mm) to arrest weathering in 'Mcs' and 'Lcm' rocks.
	Weathered unit contacts at the roof of caves.	Reinforced shotcrete 100 mm with rock bolts to stabilize the frontal and back slopes of caves.
	Seepage along the relief zone.	Stripping of soil cover in a width of 15m from the edge of caves. Treatment / sealing of surface with shotcrete (50 mm) and reclaiming/covering back with soil to maintain the natural look.
	Predominant basal set (J_1) and flow contacts causing gravity falls/deslating.	Strengthening of roof of caves with ('Mcs' and 'Lcm' rock mass) with reinforced shotcrete, anchoring etc
	Predominance of weathered (Mcs & Lcm) rock mass.	Pinning of potential wedges/layers with tension and grouted rock bolts in the roofs.
	Accentuated seepage in caves through zone of relief joints. Wedge failures in the frontals of caves with	Selective reinforced shotcrete (100 mm) with rock bolts 2 – 6 m. Spot bolts 2-3 m long tensioned & grouted.
III	potential over hang. Pronounced weathering.	Shotcrete (25-50 mm) to arrest weathering in Mcs and Lcm. Stripping of soil cover and sealing the surface up to the longitudinal drain above the cave portal and relaying of soil cover for a natural look.
IV	Potential planar failure zones along relief joints (J_4). Pronounced weathering of rock mass 'Mcs' and 'Lcm'.	Selective reinforced shotcrete with rock bolts. Shotcrete (25-50) to arrest weathering.
	Seepage along the zone of relief joints.	Stripping of soil cover selectively and sealing with shotcrete (50 mm) and relaying of soil cover up to the longitudinal drain.
	Thinning of rock cover over the caves.	Improvement of drain by locking it in the rock profile.



Plate : VI1-3

ROCK MASS DISTRIBUTION MAP OF CAVES 1-7 AT ELLORA



MOHD. J. AHMED
GEOLOGIST(Sr.)

ROCK MASS CATEGORIES

LEGEND

- Sc - SCREE
- CUT FACES
- TRACE OF EXFOLIATION JOINTS
- ZONE BOUNDARY
- Mms - Moderate strength - moderately jointed - slightly weathered
- Mcs - Moderate strength - closely jointed - slightly weathered
- Lcm - Low strength - closely jointed - moderately weathered

N.B: THE MAP IS BASED ON THE INTERPRETATION OF TERRESTRIAL STEREOPHOTOS.

Plate : VII-4

ROCK MASS DISTRIBUTION MAP OF CAVES 10-11 AT ELLORA

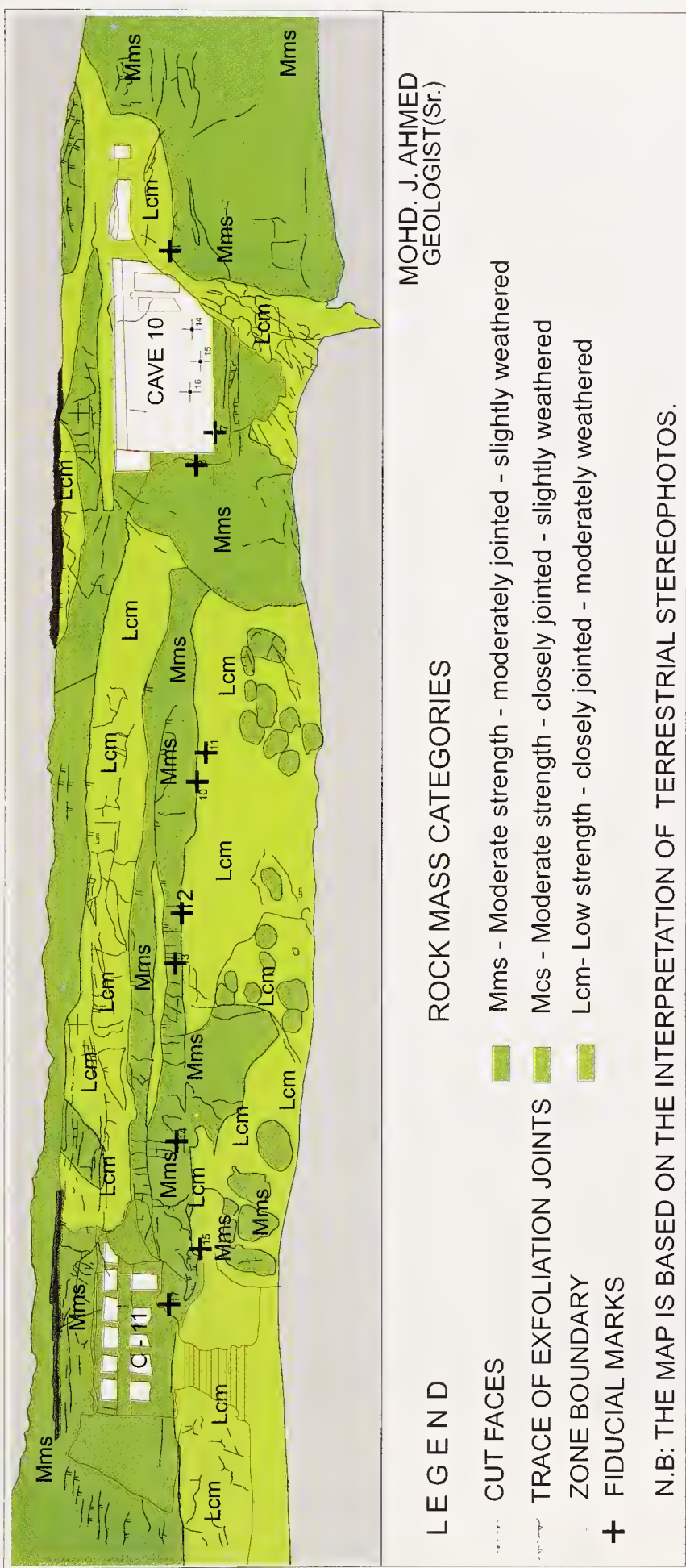


Plate : VII-5

ROCK MASS DISTRIBUTION MAP OF CAVE 12 AT ELLORA

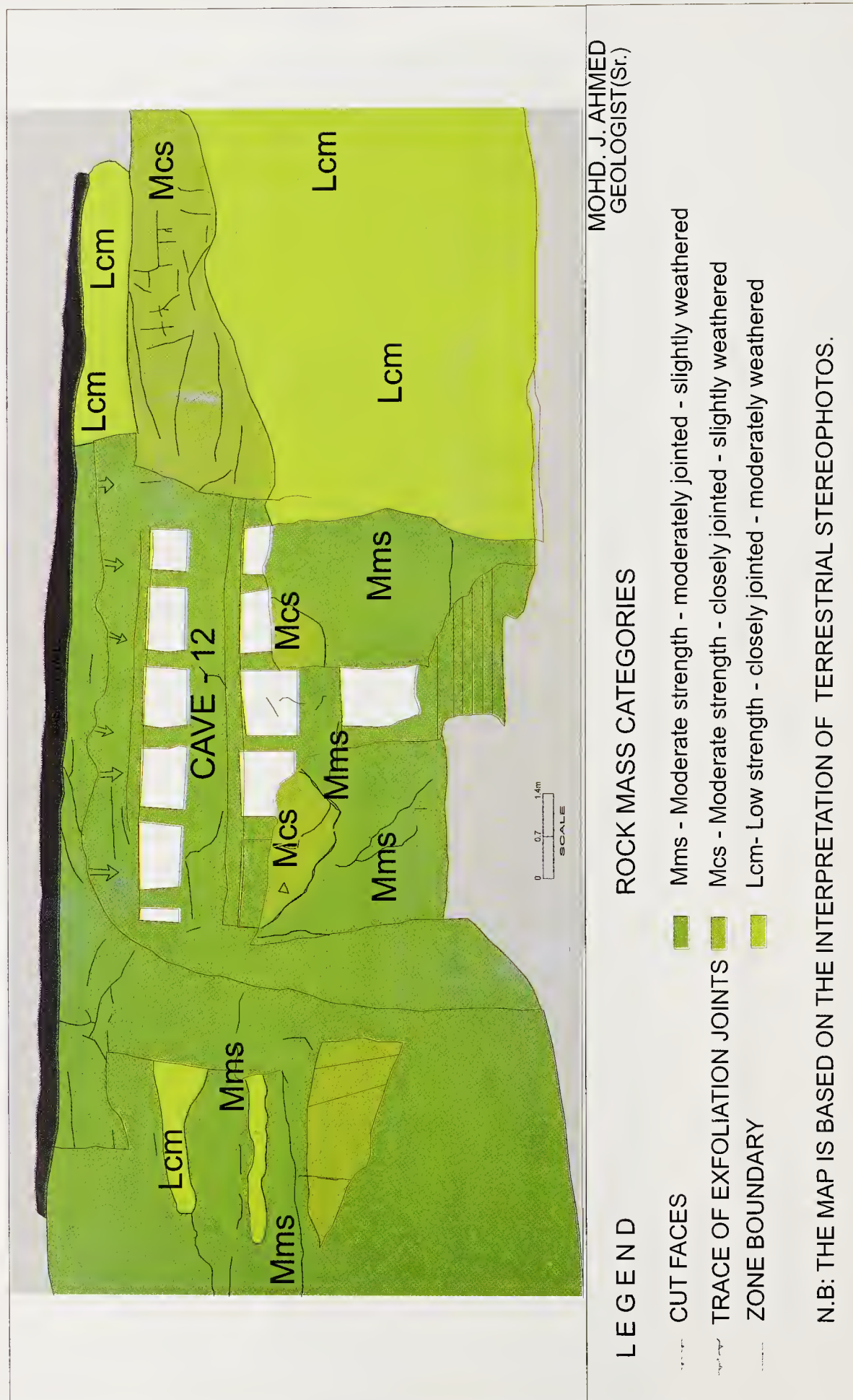
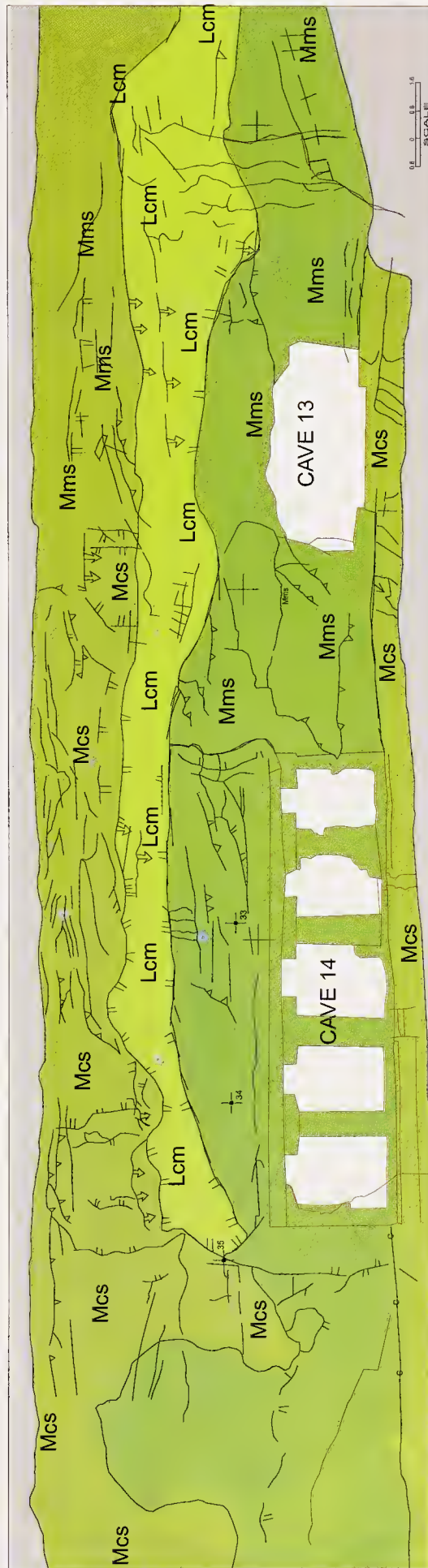


Plate : VII-6

ROCK MASS DISTRIBUTION MAP OF CAVES 13 & 14 AT ELLORA



MOHD. J. AHMED
GEOLOGIST(Sr.)

ROCK MASS CATEGORIES

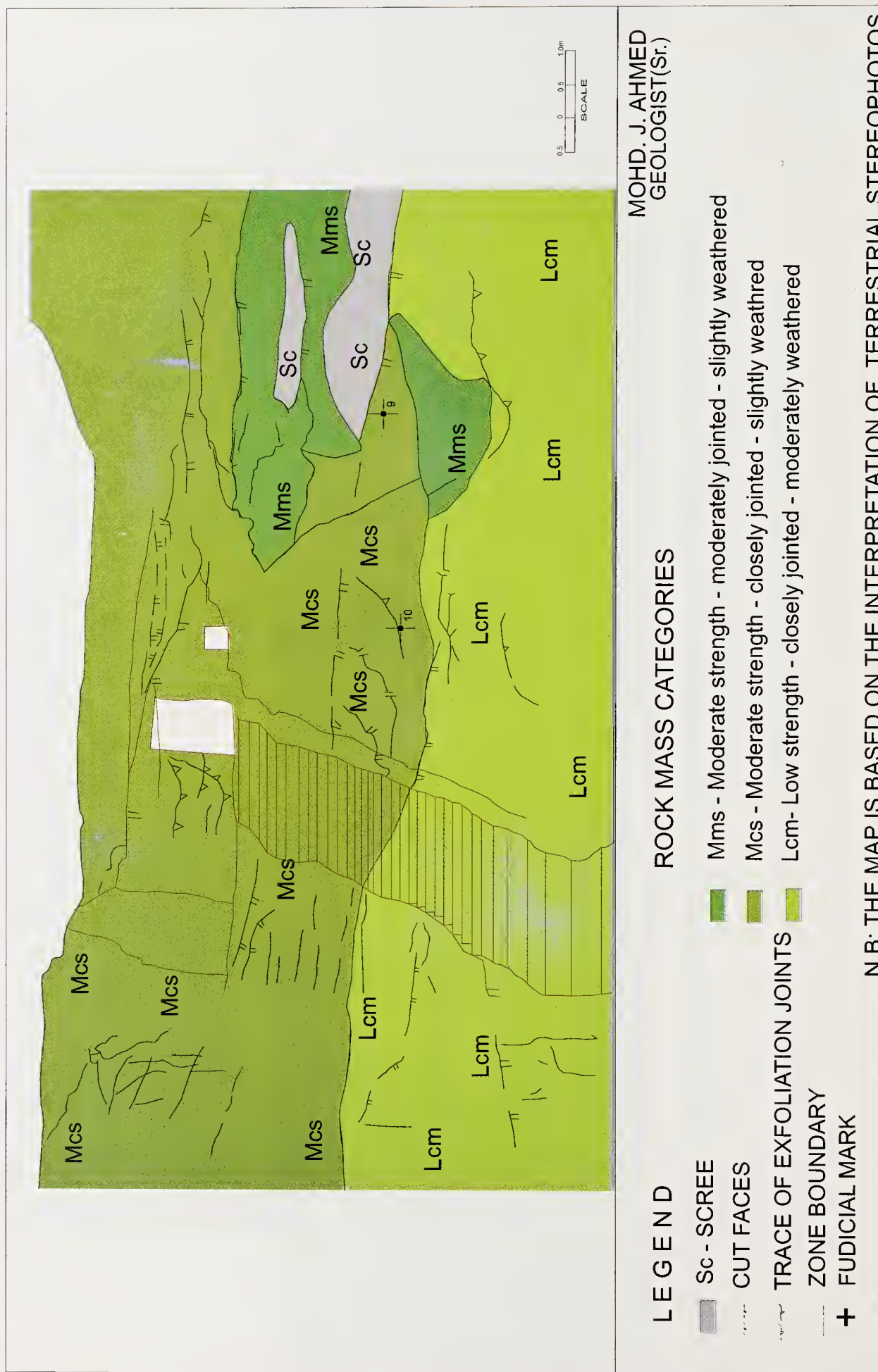
LEGEND

- CUT FACES
- TRACE OF EXFOLIATION JOINTS
- ZONE BOUNDARY
- FUDICIAL MARK

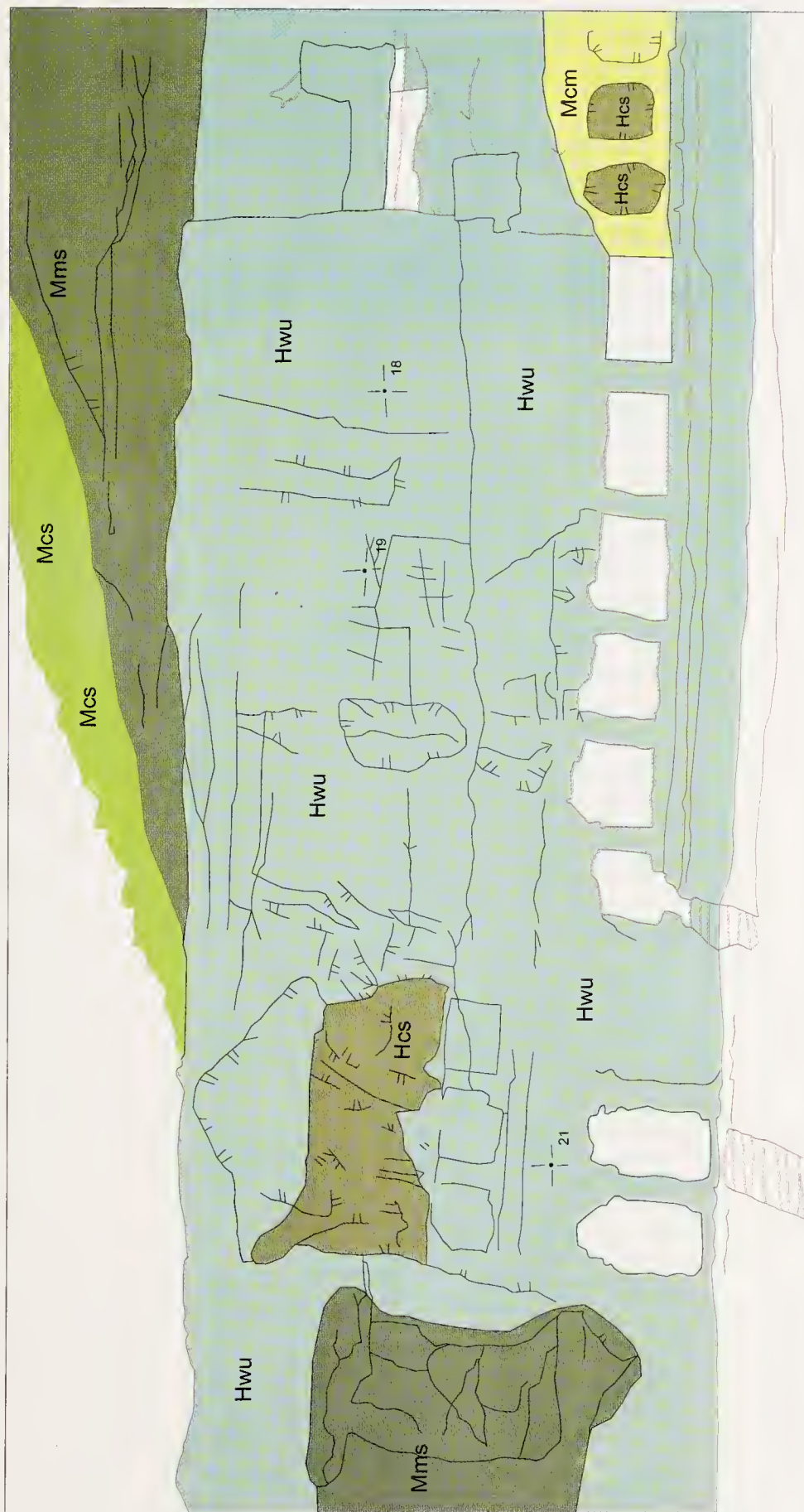
N.B: THE MAP IS BASED ON THE INTERPRETATION OF TERRESTRIAL STEREO-PHOTOS.

Plate : VII-7

ROCK MASS DISTRIBUTION MAP OF CAVE 15 AT ELLORA



ROCK MASS DISTRIBUTION MAP OF CAVE 16 AT ELLORA



LEGEND

CUT FACES

TRACE OF EXFOLIATION JOINTS

ZONE BOUNDARY

FIDUCIAL MARKS

ROCK MASS CATEGORIES

Hwu - High strength - widely jointed - unweathered / fresh

Hcs- High strength - closely jointed - slightly weathered

Mms - Moderate strength - moderately jointed - slightly weathered

Mcs - Moderate strength - closely jointed - slightly weathered

Mcm - Moderate strength - closely jointed - moderately weathered

MOHD. J. AHMED
GEOLOGIST(Sr.)

N.B :THE MAP IS BASED ON THE INTERPRETATION OF TERRESTRIAL STEREOPHOTOS.

Plate : VII-9

ROCK MASS DISTRIBUTION MAP OF CAVES 17-19 AT ELLORA

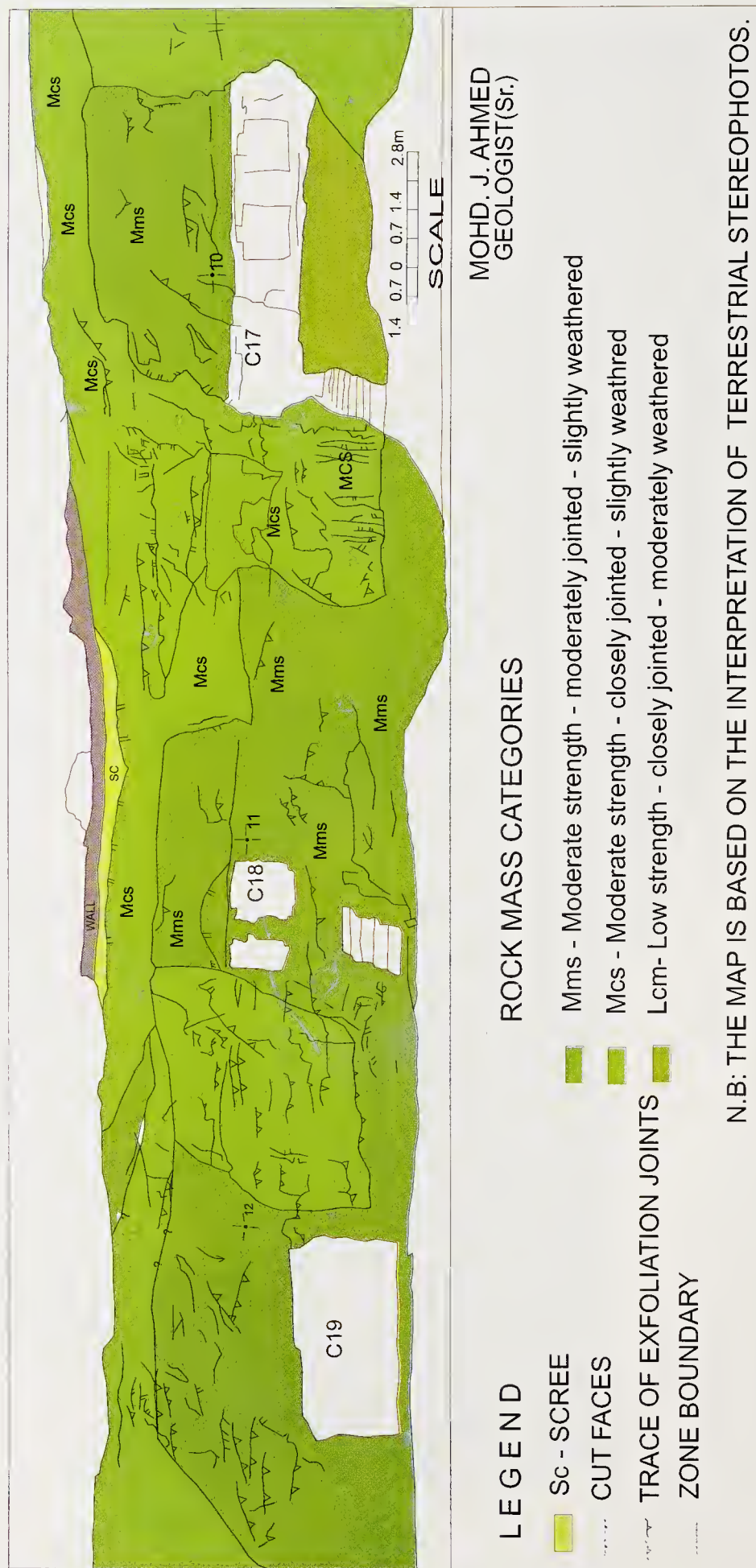


Plate : VII-10

PROPOSED SLOPE TRÉATEMENT MAP OF CAVES 1-7 AT ELLORA

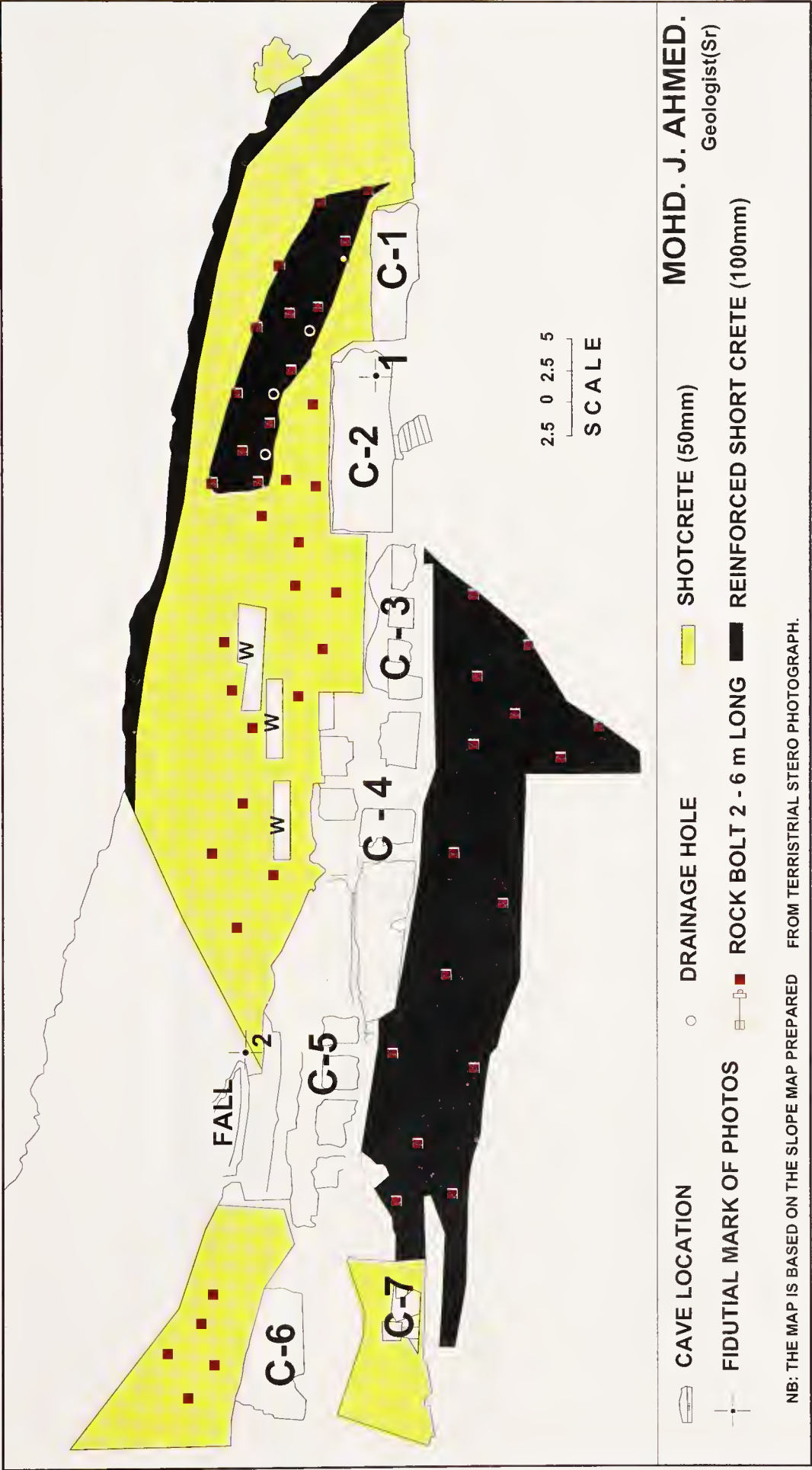
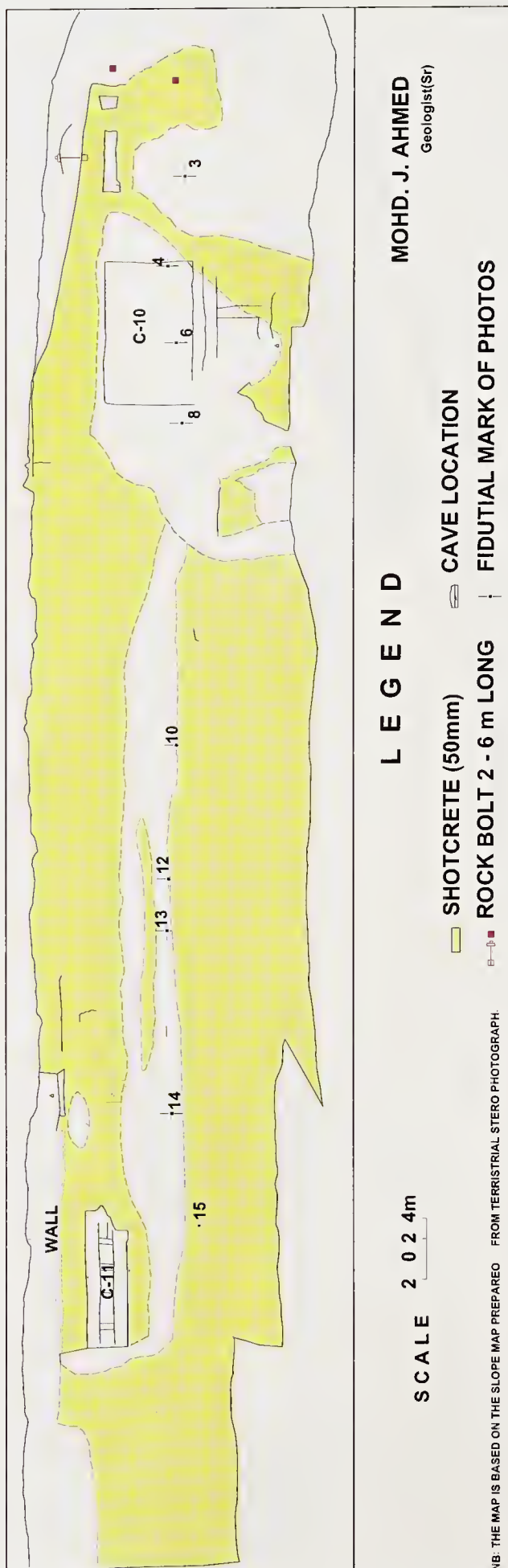


Plate : VII-11

PROPOSED SLOPE TREATMENT MAP OF CAVES 10-11 AT ELLORA



SLOPE TREATMENT MAP OF CAVE 12 AT ELLORA

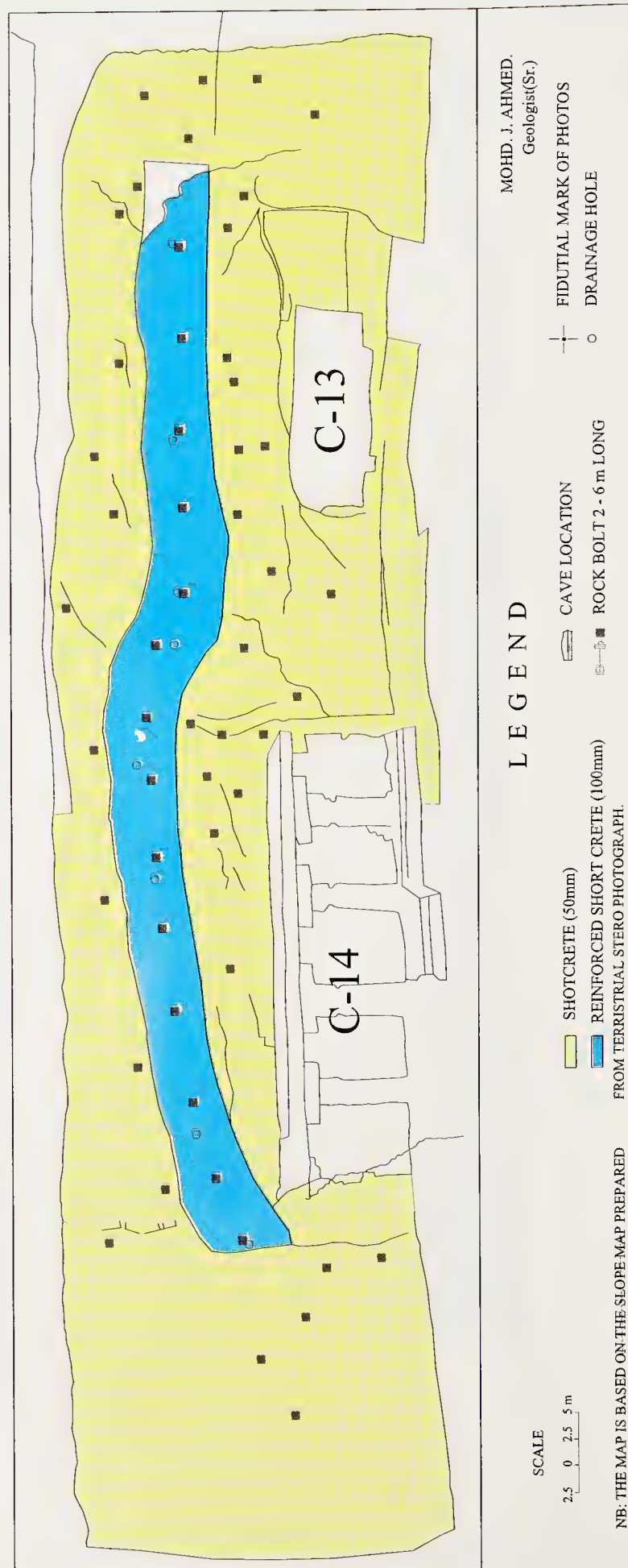


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Plate : VII-13

PROPOSED SLOPE TREATMENT MAP OF CAVES 13-14 AT ELLORA



PROPOSED SLOPE TREATMENT MAP OF CAVE 15 (SLOPES) AT ELLORA



L E G E N D

MOHD. J. AHMED.

Geologist(Sr.)

SHOTCRETE (50mm)

ROCK BOLT 2 - 6 m LONG



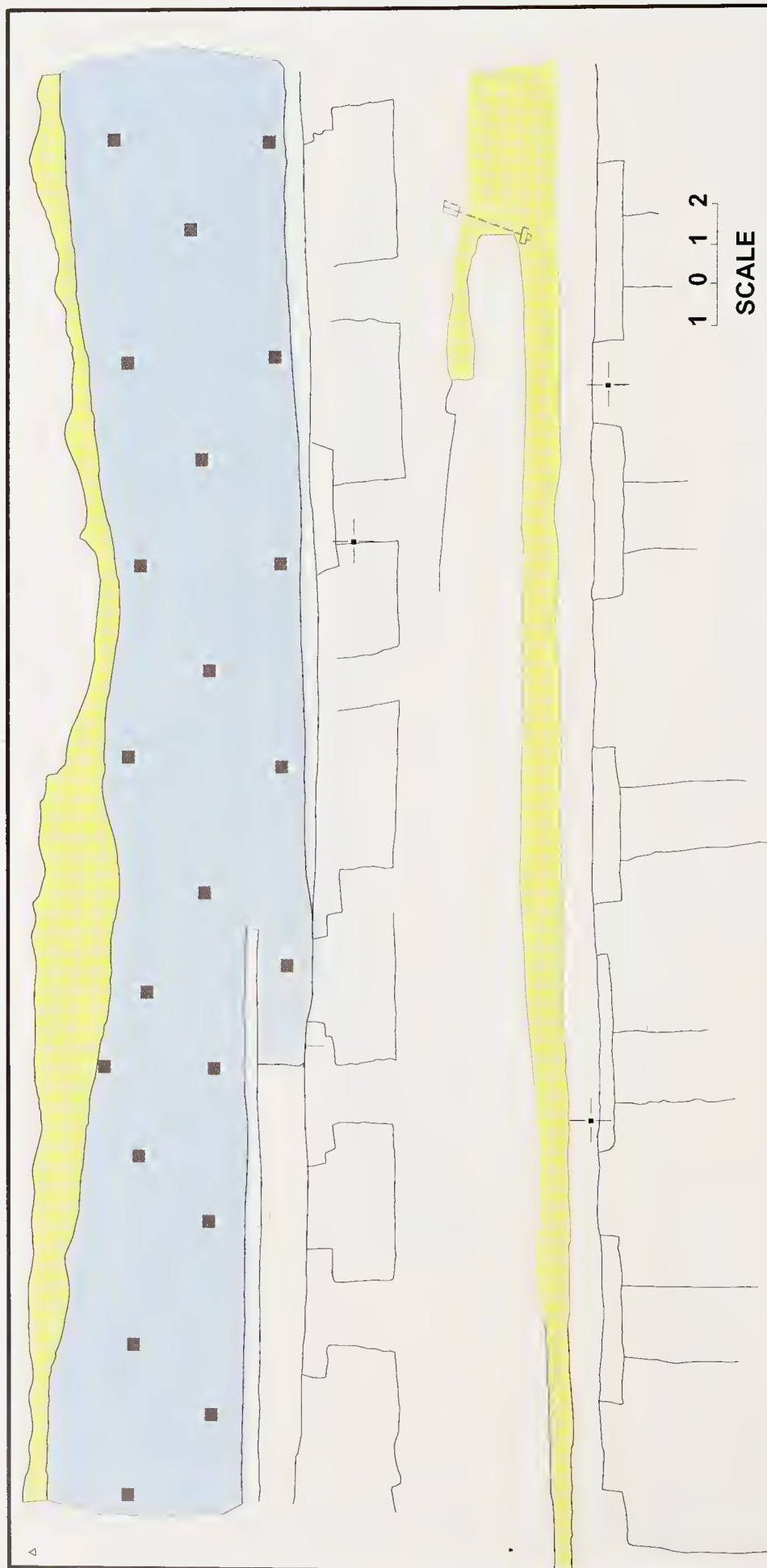
FIDUTIAL MARK OF PHOTOS



NB: THE MAP IS BASED ON THE SLOPE MAP PREPARED FROM TERRISTRIAL STERO PHOTOGRAPH.

Plate : VII-15

PROPOSED SLOPE TREATMENT MAP OF FACADE OF CAVE 15 (FACADE) AT ELLORA



LEGEND

MOHD. J. AHMED
Geologist(Sr)

- SHOTCRETE (50mm)
- REINFORCED SHORT CRETE (100mm)
- ROCK BOLT 2 - 6 m LONG
- CAVE LOCATION
- FIDUCIAL MARK OF PHOTOS

NB: THE MAP IS BASED ON THE SLOPE MAP PREPARED FROM TERRISTRIAL STERO PHOTOGRAPH.

PROPOSED SLOPE TREATMENT MAP OF CAVE 17 AT ELLORA



MOHD. J. AHMED
Geologist(Sr)

L E G E N D

2 0 2 4

SCALE

SHOTCRETE (50mm)

CAVE LOCATION

REINFORCED SHORT CRETE (100mm)

FIDUTIAL MARK OF PHOTOS

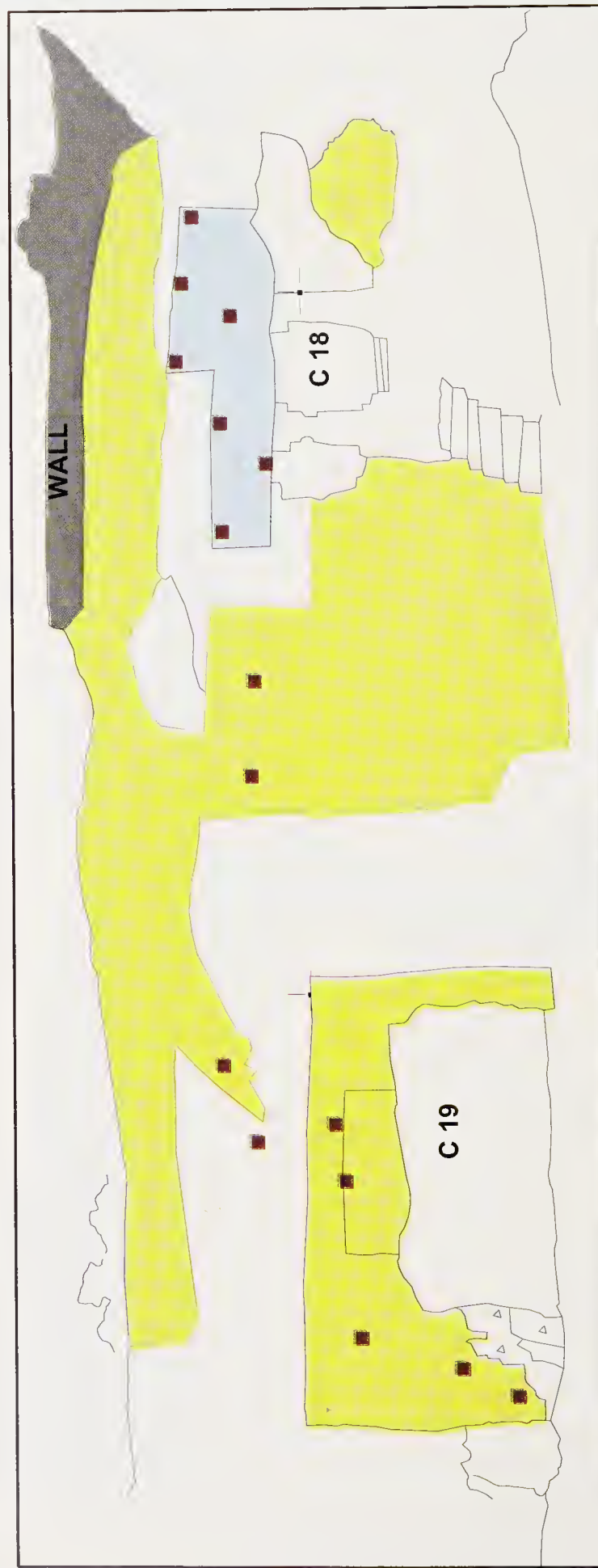
ROCK BOLT 2 - 6 m LONG

NB: THE MAP IS BASED ON THE SLOPE MAP PREPARED FROM TERRISTRIAL STERO PHOTOGRAPH.



Plate : VII-17

PROPOSED SLOPE TREATMENT MAP OF CAVES 18-19 AT ELLORA



MOHD. J. AHMED
Geologist(Sr)

LEGEND

- 2 0 2 4

SCALE
- SHOTCRETE (50mm)

REINFORCED SHORT CRETE (100mm)

CAVE LOCATION
- FIDUTIAL MARK OF PHOTOS

ROCK BOLT 2 - 6 m LONG

FIDUTIAL MARK OF PHOTOS

NB: THE MAP IS BASED ON THE SLOPE MAP PREPARED FROM TERRISTRIAL STERO PHOTOGRAPH.

PROPOSED SLOPE TREATMENT MAP OF CAVES 20-21 AT ELLORA

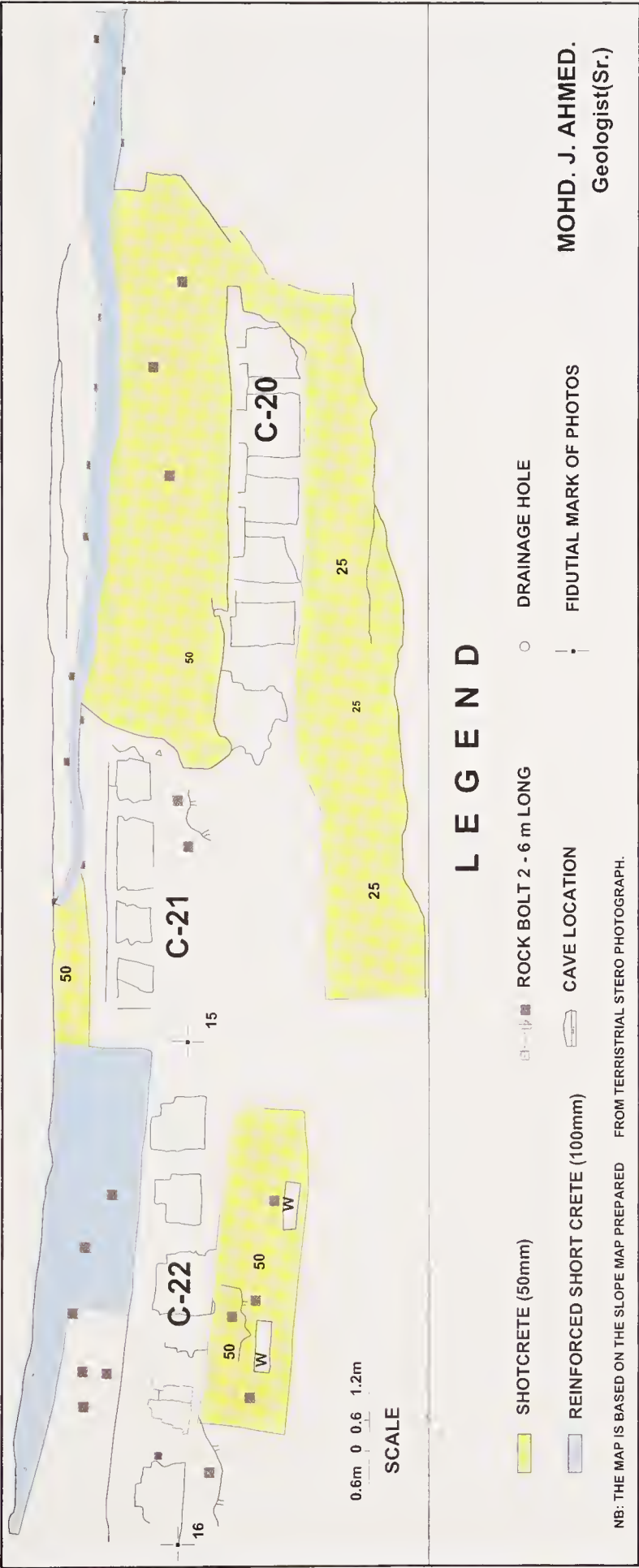


Plate : VII-19

PHOTOGRAPH SHOWING PROPOSED PROTECTION MEASURES AROUND CAVES 1 -4



PHOTOGRAPH SHOWING PROPOSED PROTECTION MEASURES FOR CAVES 4-7 AT ELLORA





Plate : VII-21

PHOTOGRAPH SHOWING PROPOSED PROTECTION MEASURES FOR CAVE 10 AT ELLORA



PHOTOGRAPH SHOWING PROPOSED PROTECTION MEASURES FOR CAVE 11 AT ELLORA

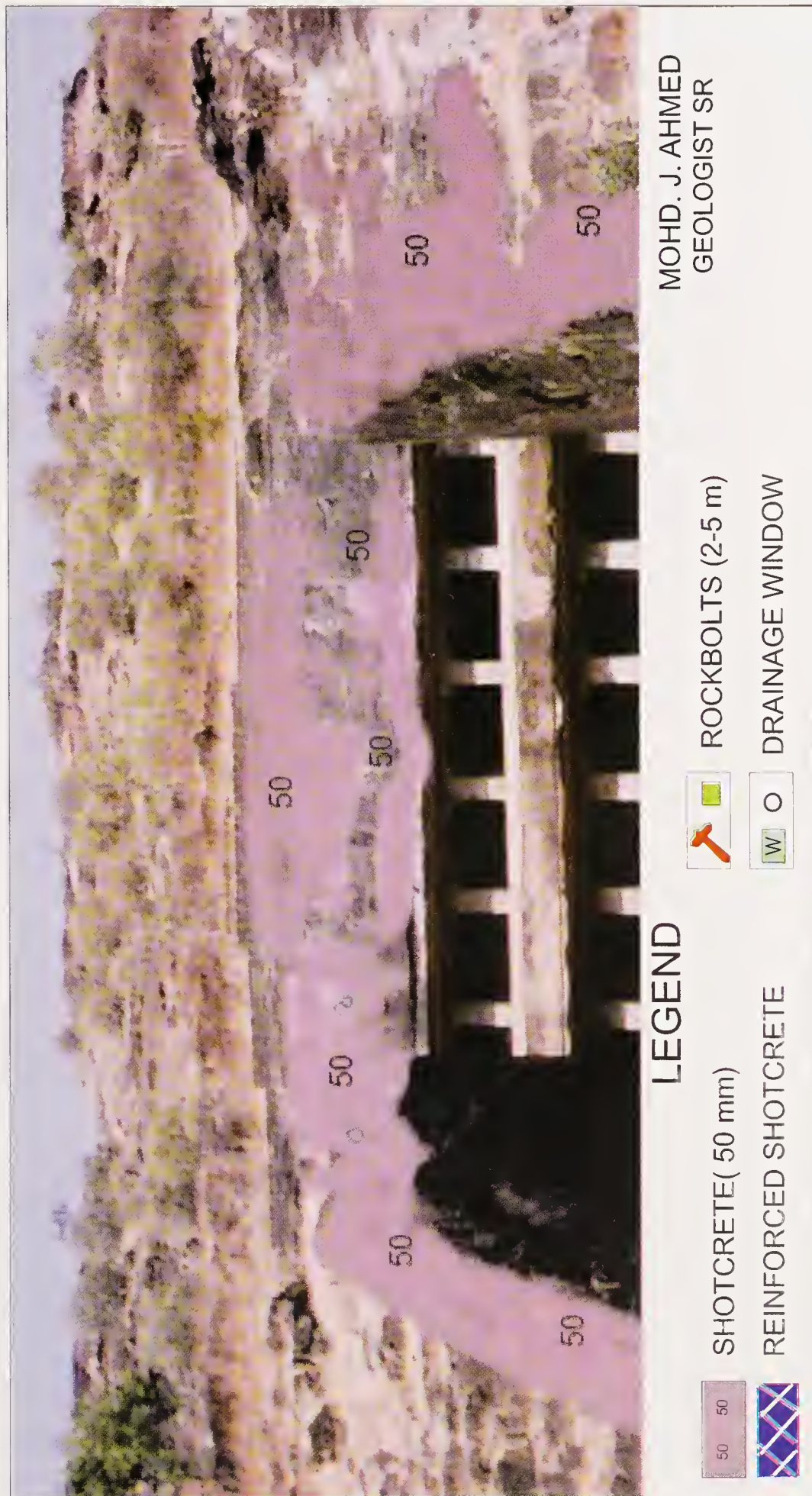
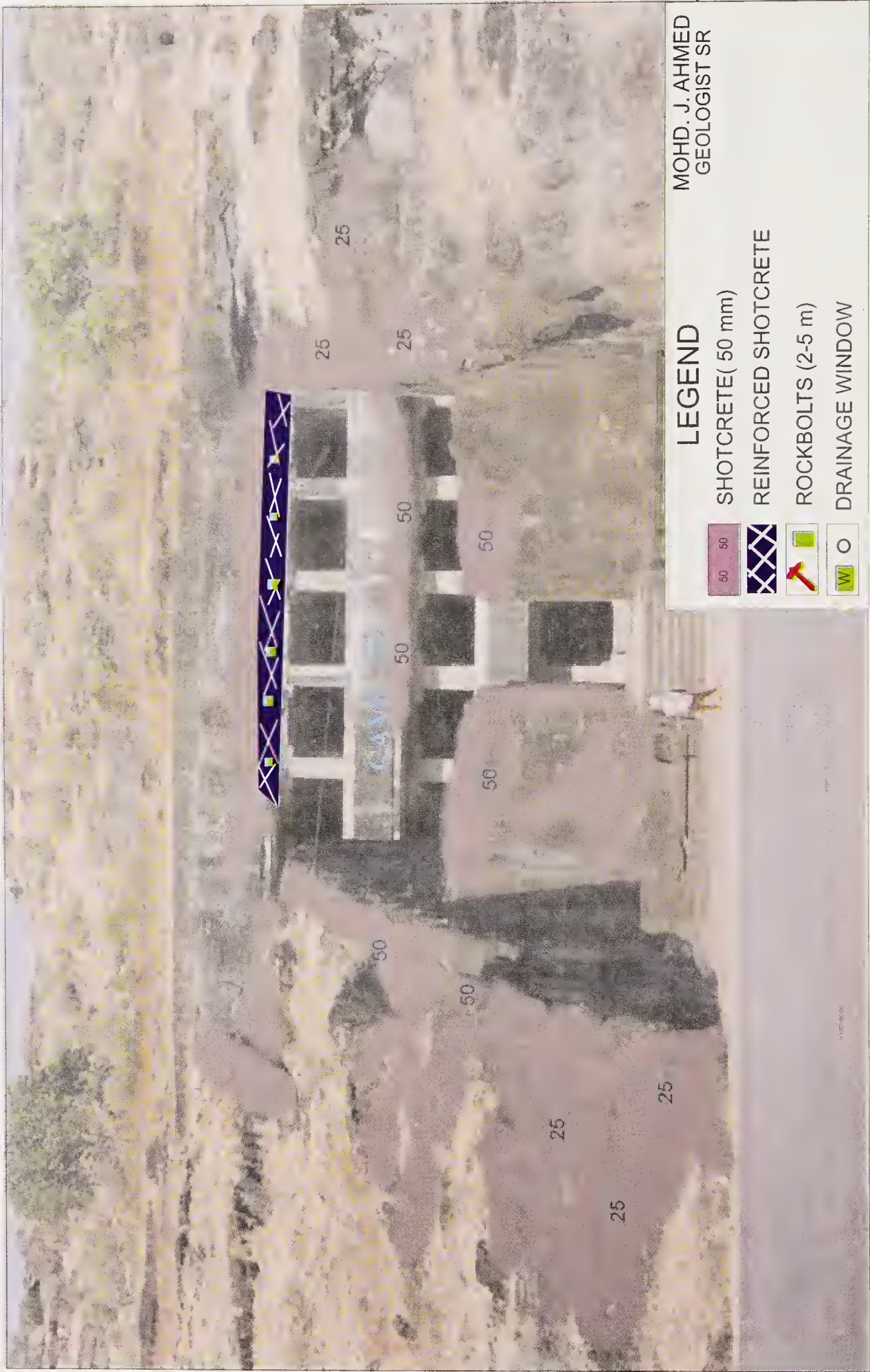




Plate : VII-23

PHOTOGRAPH SHOWING PROPOSED PROTECTION MEASURES FOR CAVE 12 AT ELLORA



PHOTOGRAPH SHOWING PROPOSED PROTECTION MEASURES FOR CAVES 13 & 14 AT ELLORA

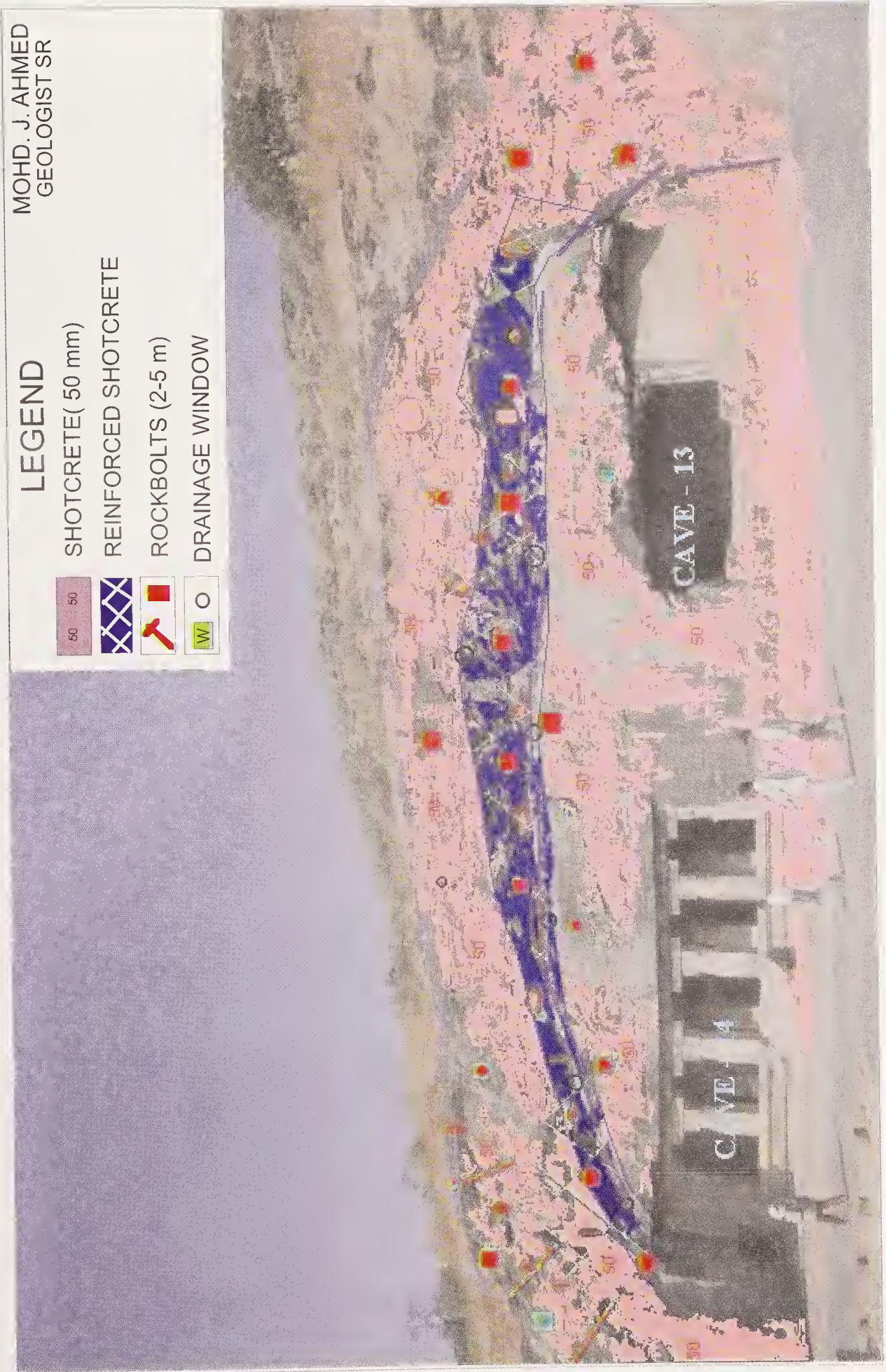


Plate : VII-25

PHOTOGRAPH SHOWING SUGGESTED PROTECTION MEASURES FOR CAVE 15 AT ELLORA



PHOTOGRAPH SHOWING PROPOSED PROTECTION MEASURES
FOR NORTHERN PART OF CAVE 16 AT ELLORA



Plate : VII-27

**PHOTOGRAPH SHOWING PROPOSED PROTECTION MEASURES FOR
NORTHERN PART OF CAVE 16 AT ELLORA**

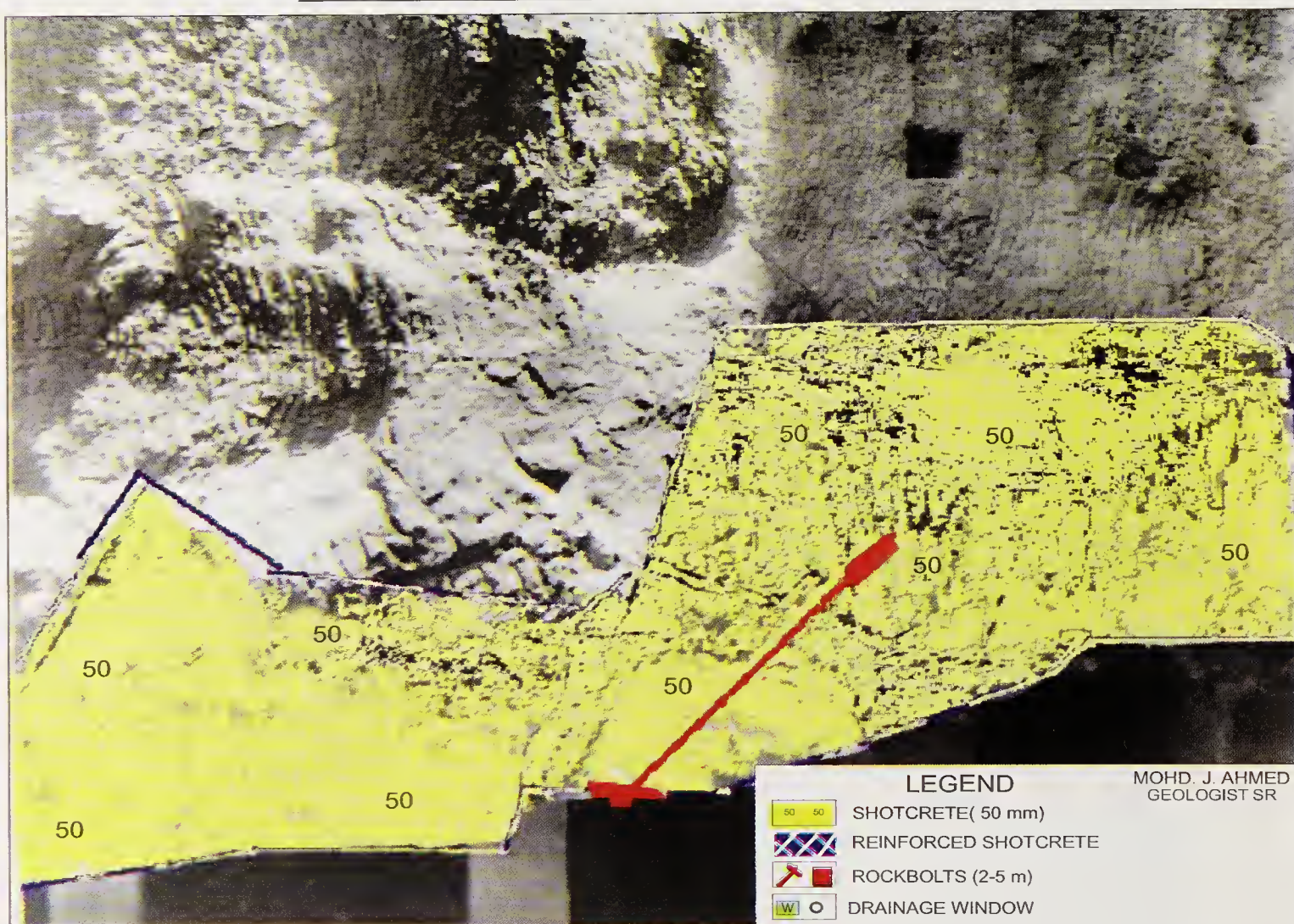


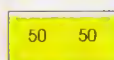
Plate : VII-28

PHOTOGRAPH SHOWING PROPOSED PROTECTION MEASURES FOR SOUTH WESTERN PART OF CAVE 16 AT ELLORA



LEGEND

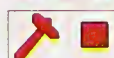
MOHD. J. AHMED
GEOLOGIST SR



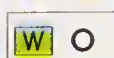
SHOTCRETE(50 mm)



REINFORCED SHOTCRETE



ROCKBOLTS (2-5 m)



DRAINAGE WINDOW

**PHOTOGRAPH SHOWING PROPOSED PROTECTION MEASURES
ON THE SOUTHERN FACE OF CAVE 16 AT ELLORA**

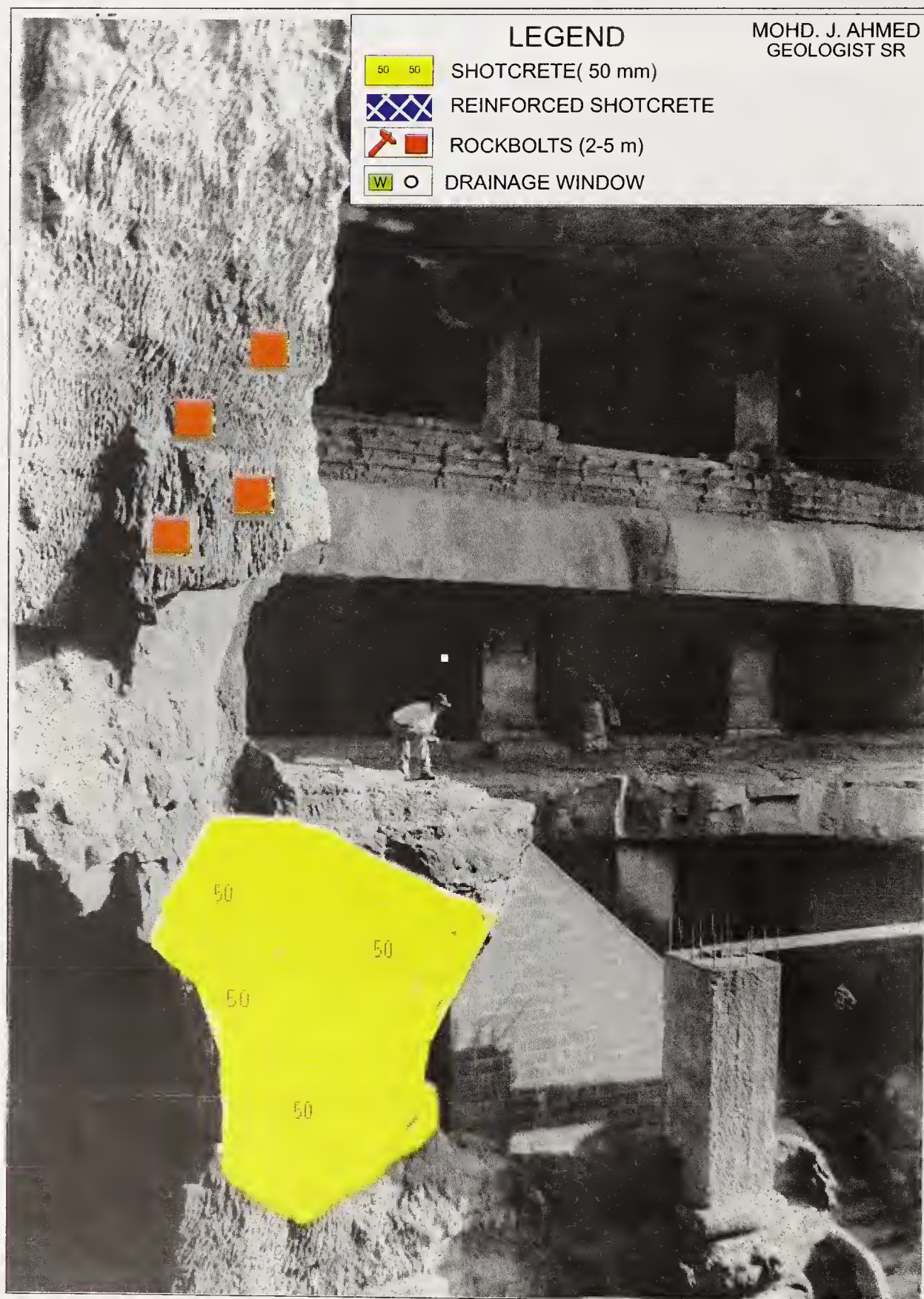


Plate : VII-30

**PHOTOGRAPH SHOWING PROPOSED PROTECTION MEASURES
ON THE SOUTHERN FACE OUTSIDE CAVE 16 AT ELLORA**



**PHOTOGRAPH SHOWING PROPOSED PROTECTION MEASURES
ON THE SOUTHERN FACE OF CAVE 16 AT ELLORA**



Plate : VII-32

PHOTOGRAPH SHOWING PROPOSED PROTECTION MEASURES
ON THE SOUTHERN FACE OF CAVE 16 AT ELLORA



Plate : VII-33

**PHOTOGRAPH SHOWING PROPOSED PROTECTION MEASURES
ON THE SOUTHERN FACE OUTSIDE CAVE 16 AT ELLORA**



Plate : VII-34

**PHOTOGRAPH SHOWING PROPOSED PROTECTION MEASURES
ON THE EASTERN FACE OF CAVE 16 AT ELLORA**



**PHOTOGRAPH SHOWING PROPOSED PROTECTION MEASURES
ON THE SOUTHERN FACE OF CAVE 16 AT ELLORA**

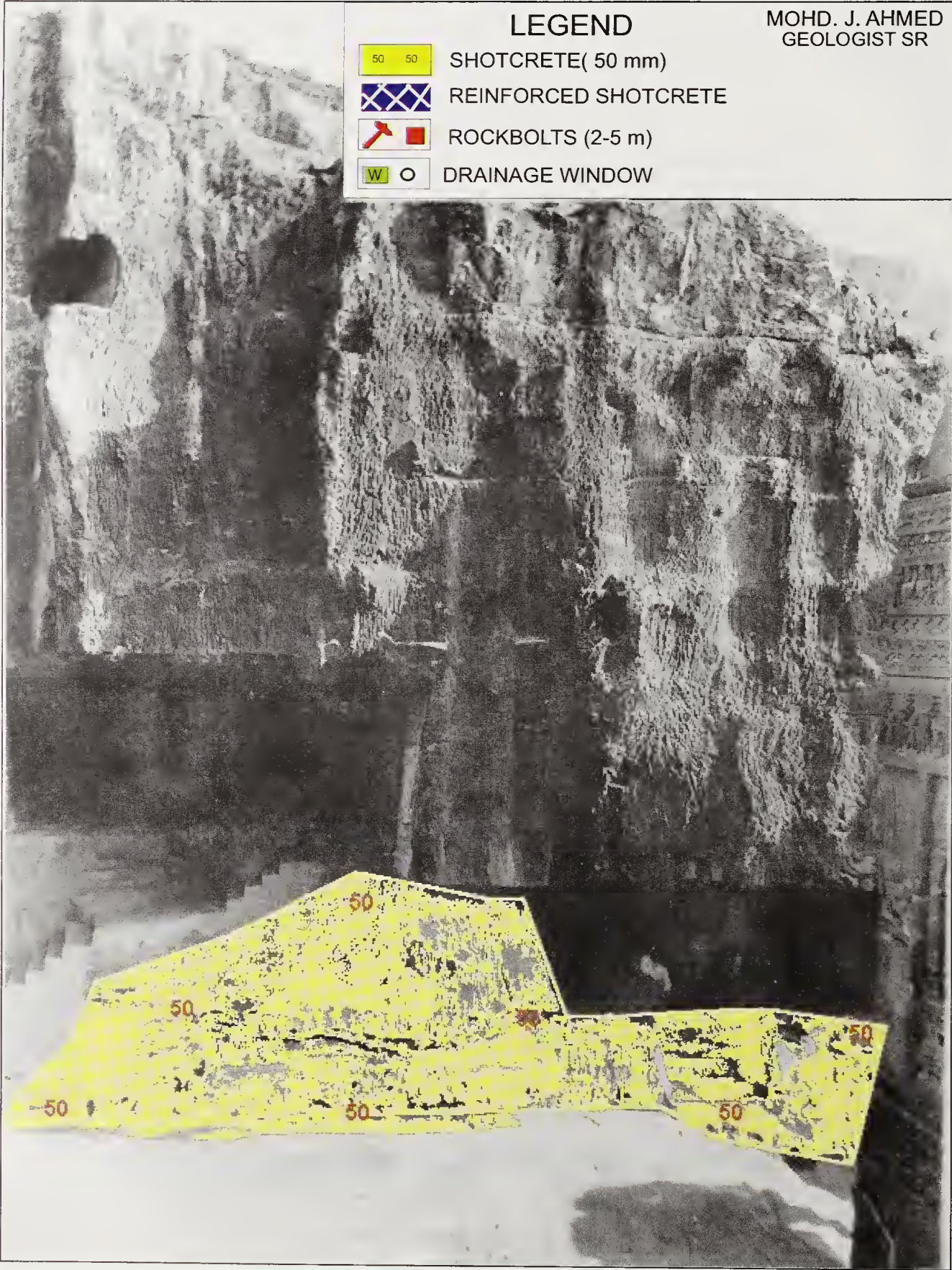




Plate : VII-37

PHOTOGRAPH SHOWING PROPOSED PROTECTION MEASURES OUTSIDE CAVE 16 AT ELLORA

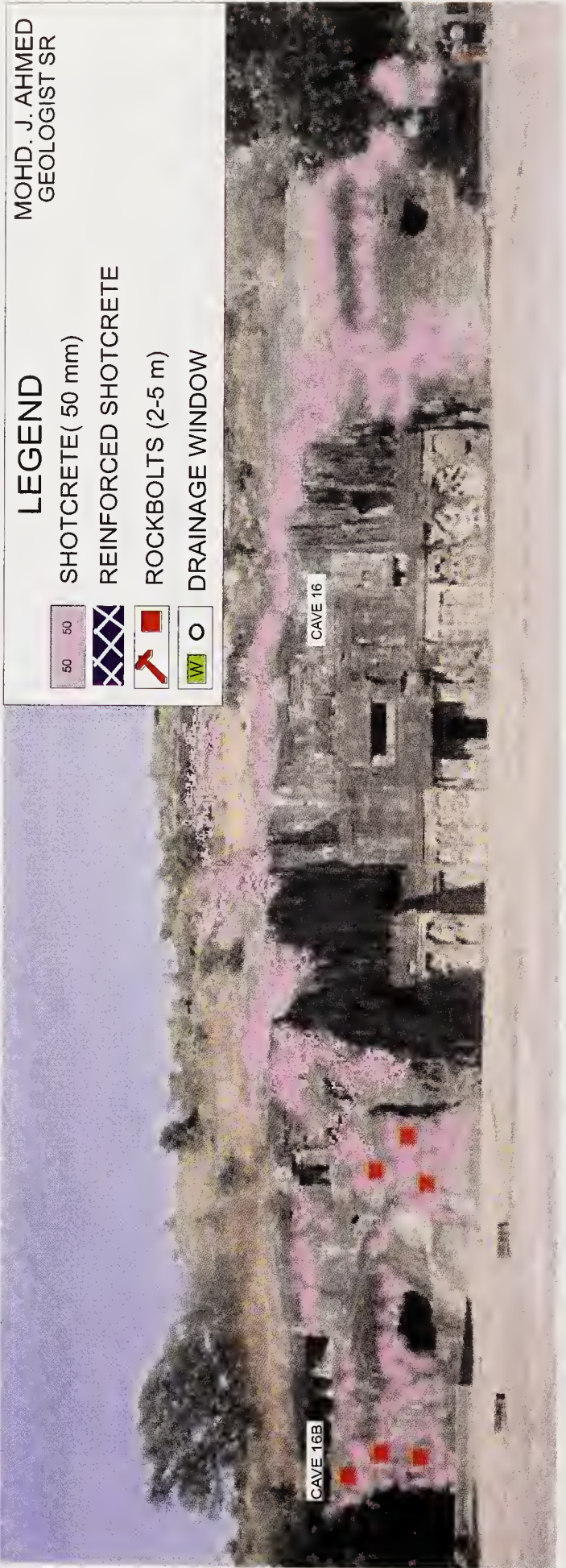
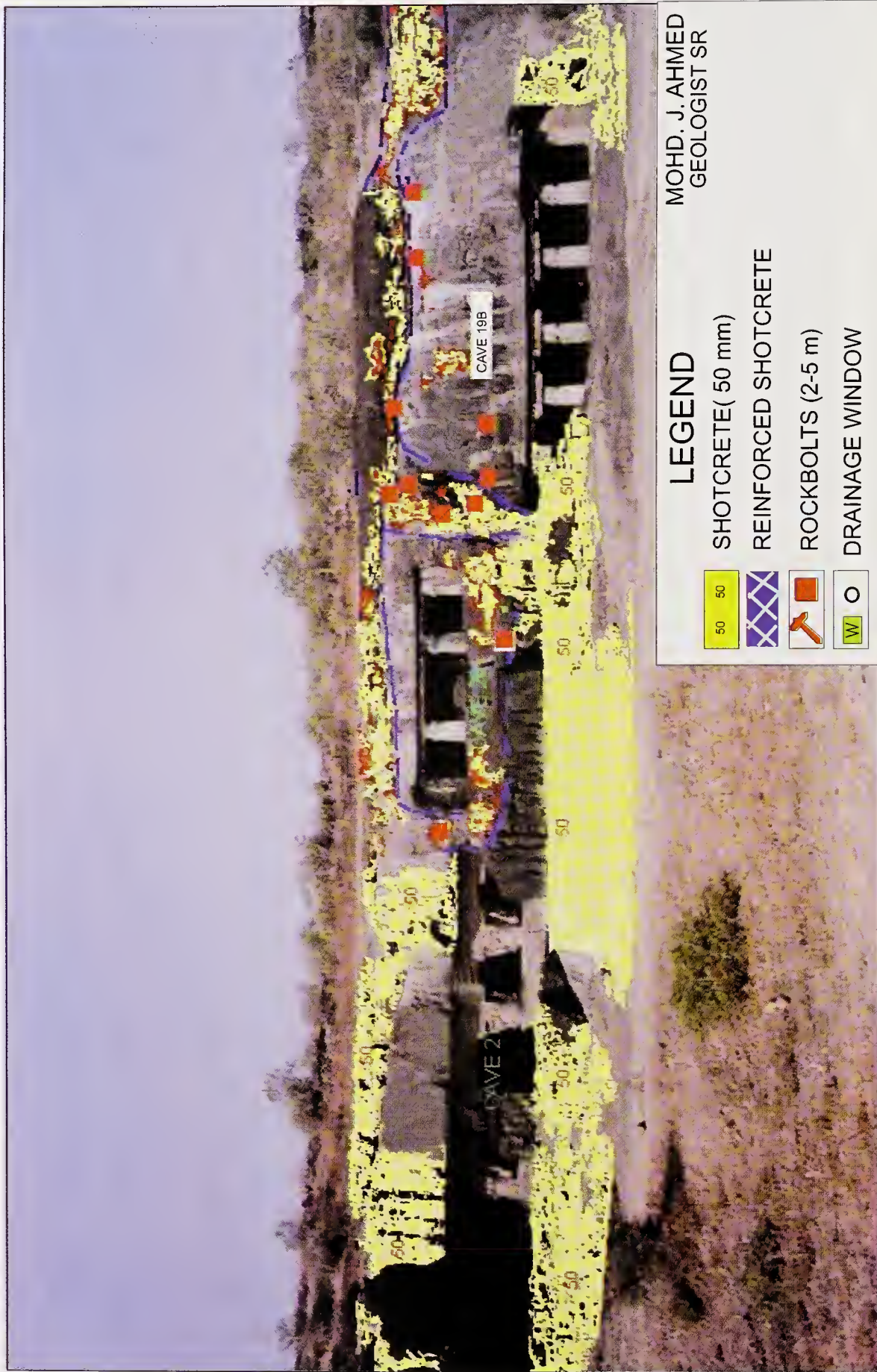


Plate : VII-39

PHOTOGRAPH SHOWING PROPOSED PROTECTION MEASURES FOR CAVES 19B -21 AT ELLORA



PHOTOGRAPH SHOWING PROPOSED PROTECTION MEASURES FOR CAVES 25 - 27 AT ELLORA

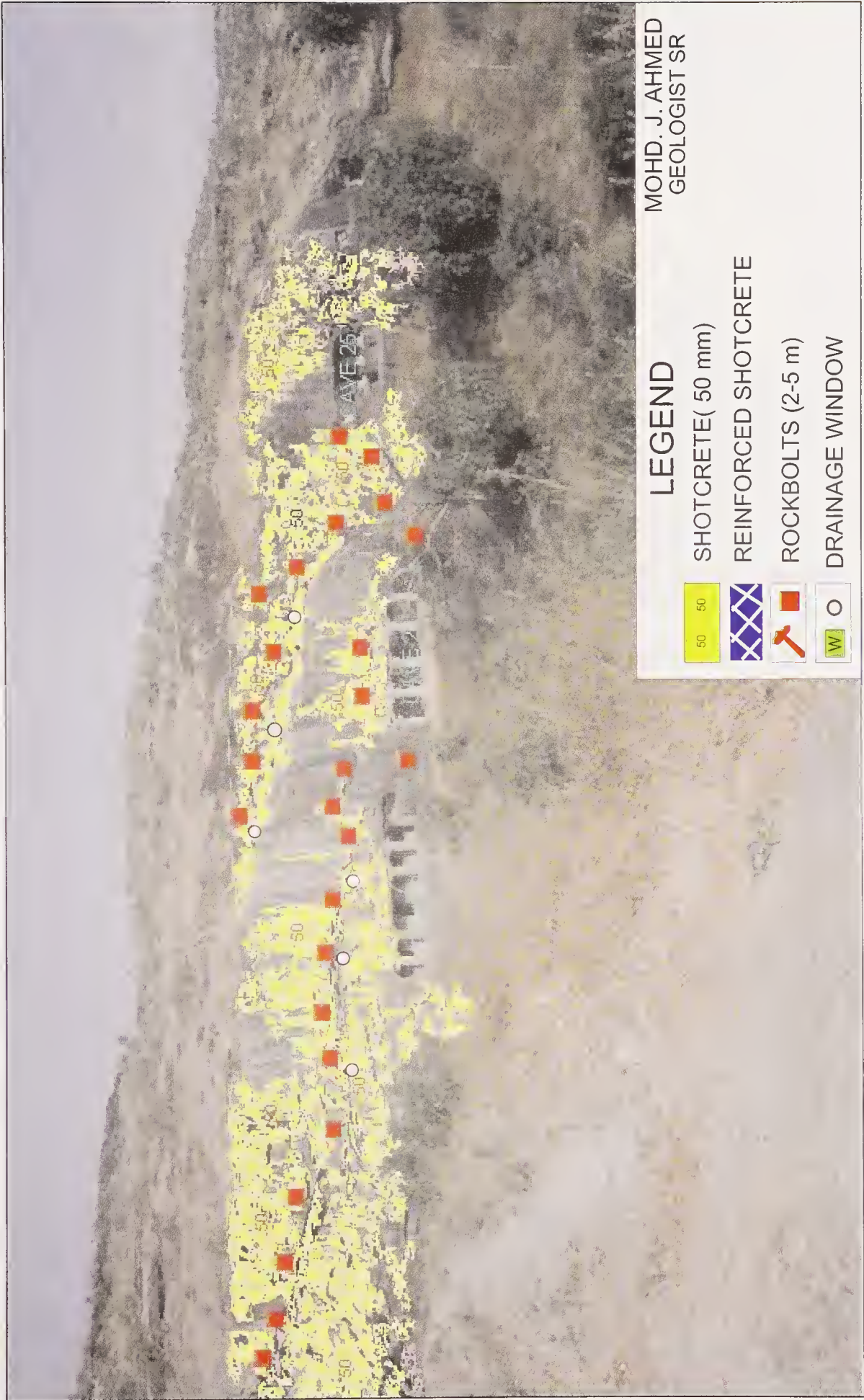




Plate : VII-41

PHOTOGRAPH SHOWING PROPOSED PROTECTION MEASURES FOR CAVE 29 AT ELLORA



PHOTOGRAPH SHOWING PROPOSED PROTECTION MEASURES IN CAVE 32 AT ELLORA





Plate : VII-43

PHOTOGRAPH SHOWING PROPOSED PROTECTION MEASURES
ON THE SOUTHERN FACE OF CAVE 32 AT ELLORA



Plate : VII-44

PHOTOGRAPH SHOWING PROPOSED PROTECTION MEASURES IN CAVE 33 AT ELLORA

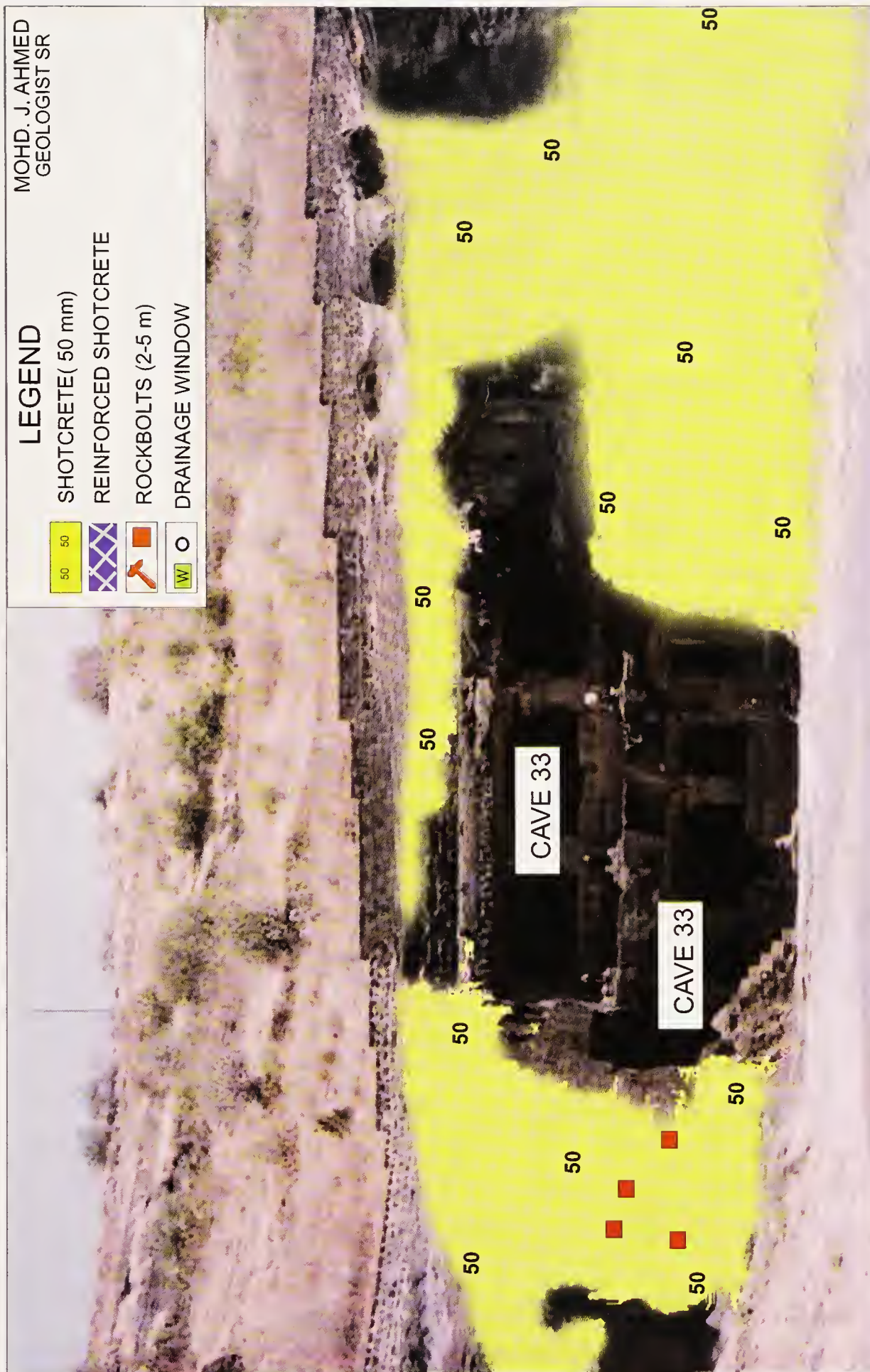


Table VII-6

QUANTITATIVE ESTIMATION OF TREATMENT MEASURES

Sector No.	CaveNo.	Shotcrete m ² (25 – 50mm)	Reinforced Shotcrete m ² (100 mm)	Rock bolt		Remarks
				<2m (length) No.	2-8m (length) No.	
I	1-7	2600	1000	50(100)	20(180)	The quantities may show a variation up to $\pm$ 20% during actual execution
II	8-16	7560	1800	120(240)	10(60)	
III	17-30	2200	550	85(170)	25(150)	
IV	31-34	7000	700	145(290)	60(360)	
	Total	19300	4050	400(800)	115(750)	

The Treatment Plan is discussed in detail cave wise and the treatments (Tr.1, 2 etc.) are as marked on the map presented in plate VII - 45.

CAVES 1 TO 5

- Tr. 1 Reinforced shotcrete with rock bolts (selective) and provision of windows for releasing water in the back slope of the caves.
- Tr. 2 Scraping of soil up to 20 m from the edge, shotcreting of surface followed by relaying of soil cover (to be stabilized using biodegradable (Jute) geo-textile, till grass grows.
- Tr. 3 Flushing of shotcrete zone with the new drain proposed and the drain to be embedded in fresh bedrock.
- Tr. 4 Rock bolting of 2 loose blocks on the crown of the cave 1.
- Tr. 5 Filling up of depressions and potholes to make it water proof and to stop pounding of water.
- Tr. 6 Providing iron rail barriers to catch rolling boulders in the middle part of main nala above cave 5.

Tr. 7 Reinforced shotcrete with galvanized mesh in the nala wall (near the water falls) below cave 5.

CAVES 6 to 9

- Tr. 8 Shotcrete of crown of cave 7 to arrest flaking and strengthening of rock with bolting.
- Tr. 9 (a) Providing rock bolts on the rock cut face of cave 6 to hold detached block in place.
- (b) Structural and architectural engineers to be consulted for design of buttress in the inter cave area (front part) of cave 7 and 8 or an alternative of it.
- Tr. 10 Shotcrete over facade of cave 9 to extend up to 5m from the top edge and covered up to the existing drain.

CAVE 10

- Tr. 11(a) Removal of old guniting above cave 10 on either side, followed by shotcreting up to existing drain (about 15m from top edge).
- (b) Rock bolting and selective shotcreting



of left cell crown lower deck and outer part of verandah.

- (c) Shotcreting of roof of cell on the left verandah.
- (d) Micro stitching of loose rock.
- (e) Repairing of beam and micro stitching.
- (f) Repairing of roofs and two outer cells on right verandah on upper deck.

CAVE 11

Tr. 12(a) Shotcreting of the façade, extending it to 20m on the top up to existing drain above cave 11.

- (b) Construction of a new drain above the shotcrete part.

Tr. 13 Training of nala (nala between cave 11 and 12)

CAVE 12

Tr. 14 (a) Rock bolting and reinforced shotcreting of façade in the topmost part.

- (b) Shotcreting to be extended up to 20m on top after scraping of soil.
- (c) Construction of a new drain above shotcrete part and discharge the water into the nala.
- (d) Plain shotcrete on rock ledge on either side of cave.
- (e) Boulder packing and shotcreting in cavities along fracture zone on sidewalls with provision for drainage holes.

CAVE 13 and 14

Tr. 15 Reinforced shotcrete with boulder packing, with provisions of drainage holes with concealed pipes in negative slopes above cave 13 and 14

Tr. 16 Plain shotcrete in front of cave 13 and 14.

Tr. 17 Shotcrete above 13 and 14, extending up to 20m from the top edge and provision of a new drain above the shotcrete portion.

CAVE 15

Tr. 18 Boulder packing and plain shotcrete on the rock ledge on both sides of staircase near entry.

Tr. 19 Shotcrete on the top extending up to Khuldabad foot track.

Tr. 20 Drain on the scarp side of Khuldabad foot-track to be lined and widened.

Tr. 21 The nala in which the drain is connected to be trained.

CAVE 16

Tr. 22 Reinforced shotcrete with rock bolts above verandah.

Tr. 23 Existing gunited surface to be removed and the area to be shotcreted.

Tr. 24 Floor to be smoothened and a slight gradient given to avoid ponding of water.

Tr. 25 Loose blocks to be dislodged and overhanging portion to be rock bolted.

Tr. 26 Rock bolting of loose rock.

Tr. 27 Incomplete RCC pillar to be removed.

Tr. 28 Gap between pillars in lower deck and crown to be reconstructed.

Tr. 29 Crown of verandah to be shotcreted and pillars to be reconstructed and strengthened.

CAVES North of cave 16

Tr. 30 Shotcrete above the caves extending up to 5m from the base of scarp and



provision of drain above shotcrete portion up to the nala in the north.

CAVE 17A and 18

- Tr. 31 Shotcrete of façade and top, up to retaining wall.
- Tr. 32 Repairing and lining of existing drain on the cave side with provision of drain holes on scarp side.
- Tr. 33 30-40m gap on roof of cave to be filled / packed with concrete.
- Tr. 34 Pillars near the porch (2 & 3m in open gap) of cave 18 to be repaired by rock stitching and guniting.

CAVE 19 to 24

- Tr. 35 Old guniting to be removed and shotcreted up to 20m (towards scarp) including nala bed.
- Tr. 36 Shotcrete up to (10m) existing drain from the edge and drain to be repaired as mentioned above for caves 17 and 18.
- Tr. 37 The existing drain to be embedded in bedrock and extended up to the nala (cave 24)
- Tr. 38 Shotcrete on top of cave 22 extending up to base of scarp.
- Tr. 39 Drain to be extended up to the nala / existing drain.
- Tr. 40 Shotcrete above cave 24 up to drain.
- Tr. 41 Shotcrete on top, up to 5m from edge.
- Tr. 42 Shotcrete of crown portion and northern wall façade, extending up to 5m from edge (cave 24 A and 24 B)
- Tr. 43 Left pillar near entrance of cave 24 B to be treated by rock stitching and guniting.

CAVE 25 to 28

- Tr. 44 Shotcrete on top of cave 25 up to 5m from the edge.
- Tr. 45 Shotcrete on top of cave 26 up to 5m from the edge.
- Tr. 46 Façade treatment of cave 27 by shotcrete and rock bolting.
- Tr. 47 Epoxy / PMC Coating for weathered sculptures / walls in cave 28.

CAVE 29

- Tr. 48 Reconstruction of pillars in the northern side (after gap / opening to sky)
- Tr. 49 Treatment of the damaged pillar in main cave by micro stitching.

CAVE 30

- Tr. 50 Shotcrete and filling of crack on top of cave.
- Tr. 51 Epoxy / PMC coating on cave top.
- Tr. 52 Shotcrete and filling of cracks on top of cave entrance.
- Tr. 53 Strengthening of distressed / damaged pillars inside the cave.

CAVE 30 A to 34

- Tr. 54 Scraping of surface and shotcrete on top and side slopes of cave 30 A
- Tr. 55 Drain to be widened and embedded in bedrock and repaired as stated earlier.
- Tr. 56 Shotcrete on top of cave 31 & 32 from edge to retaining wall and beyond up to 5m from retaining wall and filling and packing of side depressions.
- Tr. 57 Existing drain to be widened and embedded in fresh rock and repaired as stated earlier.
- Tr. 58 Shotcrete on top of cave 33 & 34 and proper lining of existing drain channel.



GEOTECHNICAL INVESTIGATION OF CAVES

Geotechnical studies were carried out inside the caves to incorporate details of joints, fracture zones on the crown of the cave, micro and macro scale features which may have possible bearing on the stability of caves, infiltration and seepage zones.

Details of geology, unit contacts and structural features like joints / cracks etc, occurring on the crown portion of caves have been plotted on 1: 50 scale. The points have first been transferred from the crown to the ground using a plumb bob. A device has been designed and fabricated for transferring the points in high caves using a laser pointer and adjustable tripod.

A system of grading of these cracks on the basis of hazard potential has been devised and all the cracks/ fractures have been graded on a scale of 5. The factors, which have been taken into consideration during grading, are: the length of the crack, its orientation (whether it is parallel to the scarp or transverse to it), the aperture, healing, filling, depth, roughness and inclination (shallower the angle, greater the hazard).

In this scale, category I represents stable / hairline fractures or linear features without any opening. These have the least hazard potential. Categories II, III and IV represent intermediate hazard potential areas. At the other end of the scale, category V represents unstable / open cracks/ sections where treatment may be required. Category V represents highest hazard potential.

The following terms have been used in the description of the caves.

APSE: A semicircular or polygonal recess in a church or basilica.

NAVE: The middle or main body of the basilica rising above the aisles.

AISLE: Side division of the nave or other part of the church or similar building, generally separated by pillars.

CELL: A small room in a prison or monastery, a hermits one room dwelling.

ANTECHAMBER: A chamber or room leading to the chief apartment.

PORCH: Building forming an enclosure for a doorway, portico or colonnade.

VERANDAH: A roofed gallery, terrace or open portico along the front or sides of a building.

HALL: The main room in a house or building.

CHAPEL: A place of worship inferior or subordinate to a regular church or attached to a house or institution.

DECK: a floor, platform or tier in a bus or bridge, etc.

CROWN: Top of anything as a head, hat, tree or arch.

ROOF: The top covering of a building or vehicle, the overhead surface, structure or stratum of a vault, arch, cave, etc.

CHAITYA- GRIHA: Sanctuary

VIHARA: Monastery

The usage of left side or right side refers to the side of the observer while facing towards the inside of the cave or parts of the cave.

The centerline or axis of the cave is the line connecting the center point between the central pillars of the verandah and the center point between the walls of the shrine (In most caves it

Plate : VII-45

TREATMENT PLAN MAP OF ELLORA CAVES AREA





coincides with the wheel of law or 'Dharma Chakra').

The rock quality determination was carried out at a few places within and outside the caves. The rock quality was found to be uniformly good inside caves, except in a few places where rock cover was very thin or parts of cave very close to the slope and where the rock quality is poor, owing to the presence of highly fractured zone with close spaced joints / cracks.

Plaster and paint removal can be seen along cracks, unit contacts vugs etc. Sculptures at lower level (within reach of the human hand) have lost detail (sharpness) and in some cases original form. Sculptures above 2m are generally in good shape. The destruction of both paintings and sculpture at the lower level is probably due to anthropogenic interference.

Besides, an assessment of the damages sustained by the caves has also been carried out and is presented in the form of a table at the end of the section (Table VII-7). The assessment has been done cave wise and lists the location of the problem area, the nature of structural adjustment, whether it has already taken place or whether these are potential zones, the effect on the paintings and sculptures and the probable causes, the grades of weathering, anthropogenic activity subsequent to the excavation, effects of biogenic activity and the nature and extent of seepage related damage.

A brief geotechnical description of the caves is discussed in the following paragraph. At the end of the description of each cave, all the suggested treatment measures both within and outside the caves are listed. A number of plates are also inserted at the end of the cave wise description. The geological logs of crowns of caves 1 to 16 were

prepared on 1:50 scale and then digitized and reduced to A4 size for ready reference. The geological logs of crowns of caves 17 to 34 were prepared on 1:200 scale. A few of the cells in various caves that do not contain even a single crack have been omitted from the drawings for maintaining clarity. The index shown in the plates is a comprehensive index and some of the caves may not show all the components listed therein.

CAVE - 1

Cave 1 is a simple 'vihara' with eight cells, four each on the right and back walls. Three pillars, all of which have now perished, once supported the entrance. Outside there may have been other structures like a verandah or portico with a raised plinth and cells at each end. The portico must have been supported by pillars in front but these structures have now been obliterated. On the right, there is a small cistern for storage of water. In the outer 9 m, all structures have been destroyed.

Above the entrance of the cave, weathering has resulted in creation of an overhang. In the overhang some portions have been dislocated (Plate VII – 48). A few feet above the entrance a water channel has been made for diverting the water. The façade of cave 1 can be divided in to three zones. The lower one immediately above the crown of the cave and up to the drain shows moderately weathered rock. Biogenic growth in the form of moss and small plants is noted in this zone. Water seepage in the form of droplets can be seen from numerous places through the cracks developed in the weathered rock. The second zone extends from the drainage up to the negative slope. The negative slope has developed due to differential weathering in the highly fractured zone (N10°-15° E / 45-50° NW). This highly fractured zone forms the conduit for water, which



infiltrates at the ground level. The third zone is above the negative slope and forms an overhang. There is no dripping from this zone.

The two columns at either end of the entrance and the left wall of the cave have been plastered. The entrances to the cells have been partially replastered. The floor of the cells has also been cemented.

Most of the cracks that have developed in the hall of the cave are in the outer half. At places flaking can be seen. Near the entrance one small block has started to detach and may fall at any time (Plate VII – 48). Unit contact can be seen at a height of about 2 m on the front and right walls. The pillars at the entrance appear to have collapsed along a unit contact. Towards the rear of the hall, trace of unit contact can be seen on the crown.

There are four cells on the right side of the main hall. The first cell on the right is an incomplete one. On the crown, water seepage along a fracture to the right of the entrance has resulted in the deposition of calcium carbonate in layers. At one or two places small stalactites (1-2 cm) have been formed (Plate VII – 48).

Unit contact is seen at a height of about 0.6 – 1.2 m from the floor (which is uneven). Portions of the crown appear to be flaking. In the second cell, unit contacts are seen at two levels. The lower one is almost at floor level while the upper one is at a height of 0.6 – 1.2 m from the floor. Thin quartz/ zeolite veins and zeolite vugs are seen at one or two places. The crown contains two fractures, one of which falls in category III. In the third cell, unit contact can be seen at a height of 0.6 – 1.0 m from the base. Pipe amygdulites are present. A hollow tube, horizontal in disposition, having a diameter of about 15 cm and a length of about 1m can be seen on the back wall. The fourth cell has been left incomplete and its floor is uneven. Unit contact is seen at a height of about 50 cm from the floor.

In the four cells on the back wall only minor fractures can be seen. At places remnants of plaster can be observed sticking to the walls. Unit contact is not visible.

Water seepage in the cave is restricted to the outer 1-2 m of the hall and the first cell on the right. Seepage is through a vertical crack (trending N50°E). In the hall the seepage is in the form of droplets while in the cell there is a continuous drip.

The rock outside the cave in an area 4-5 m from the entrance shows Grade III to IV weathering. The front 3 m of the cave shows Grade III weathering on the crown. In the next 2 – 3 m Grade II weathering is seen. The remaining part of the cave shows Grade I weathering.

Treatments suggested are as follows:

- 1) Reinforced shotcrete with rock bolts above cave 1 & 2 and selective shotcrete near the top of edge. Provision of windows and drainage at places.
- 2) Scraping of the top surface to expose fresh rock up to an area of 20m from the edge, followed by shotcreting the surface. Stripping of soil in this zone followed by laying of an impervious layer (geo-synthetic or shotcrete) and later followed by re-laying of the stripped soil with grass cover will adequately take care of the water seepage. A drain embedded in bedrock should be constructed at the upper end of the shotcreted zone.
- 3) Bolting of the loose blocks on the crown of cave 1.
- 4) Load tests to be carried out in caves 1, 7 & 25 in view of the large unsupported spans.

The geological log of the crown of cave 1 is presented in plate VII – 46 and section along the centerline is presented in plate VII - 47.

GEOLOGICAL LOG OF CROWN OF CAVE 1 AT ELLORA



INDEX

	SLIGHTLY WEATHERED VESICULAR BASALT
	TRACE OF UNIT CONTACT / SQUEEZE UPS
	TRACE OF CRACKS/ FRACTURES
	WATER SEEPAGE ZONES
	PLASTERED CRACKS
HAZARD GRADATION OF CRACKS	
	CATEGORY I
	CATEGORY II
	CATEGORY III
	CATEGORY IV
	CATEGORY V
	UNSTABLE AREAS WHERE TREATMENT IS REQUIRED
R. L. OF FLOOR: 623.27m R. L. OF CROWN: 626.02m SHEETS: 1	
MAPPED BY: Dr. C. Joshi Geologist Jr.	

Plate : VII-47

GEOLOGICAL CROSS SECTION ALONG THE CENTRE LINE OF CAVE 1 AT ELLORA

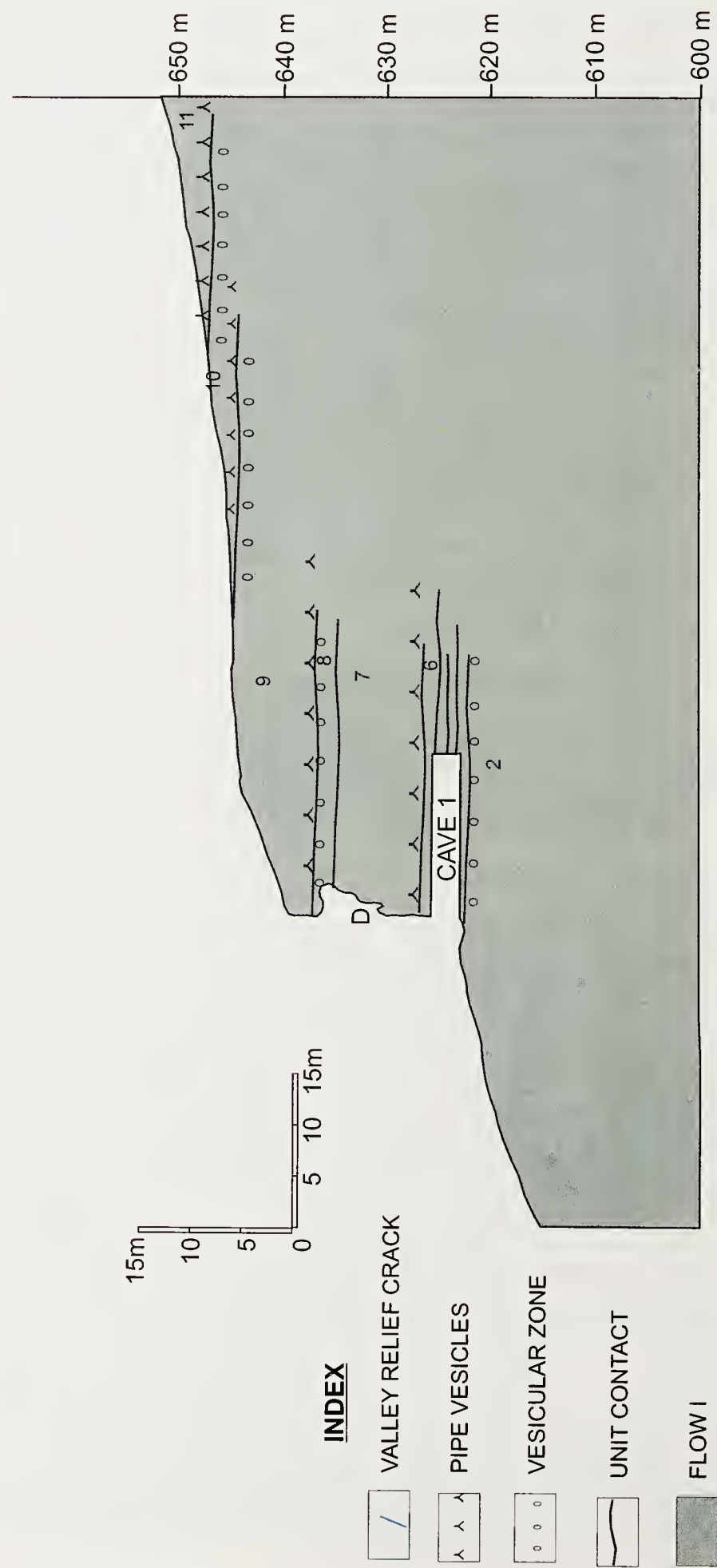
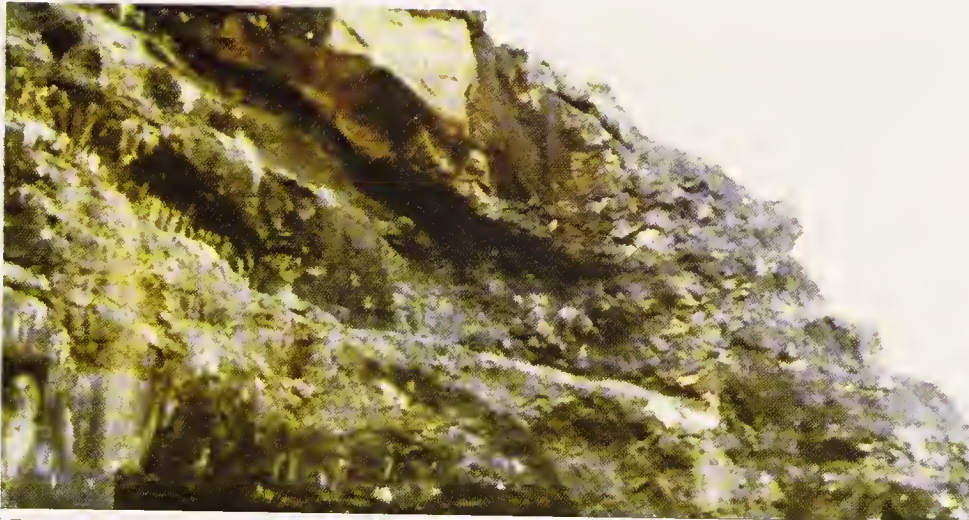
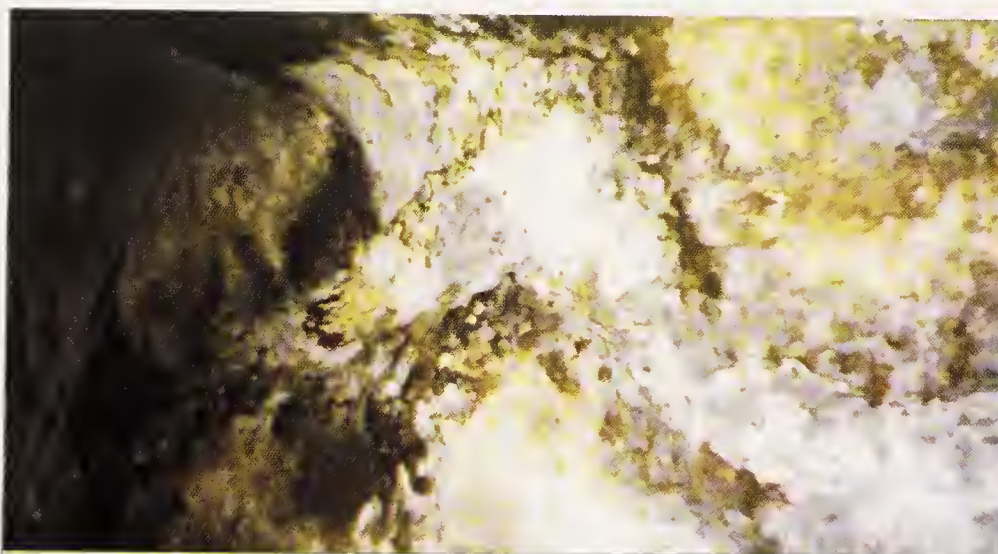


Plate : VII-48



DIFFERENTIAL WEATHERING ALONG FRACTURED ZONE HAS GIVEN RISE TO OVERHANG

ROCK MASS IN THE PROCESS OF BEING DISLODGED ON CROWN OF CAVE 1



WATER SEEPAGE IN CAVE 1



CAVE - 2

Cave 2 appears to be a 'Chaitya' and has an open verandah with a small overhanging roof without support. The crown of the overhang and part of the façade have been plastered. In the overhanging verandah water seepage is seen through a crack on the right side. At the edge of the plastered portion water seepage in the form of a near continuous drip is seen through small drainage holes. The façade of cave 2 can be divided into three zones. The lower zone consists of the plastered portion. Above this, the weathered rock forms the second zone. This zone is fed by rainwater percolating down the highly fractured zone and water from the drain that feeds the weathered rock concealed by plastering in the lower zone. The upper zone forms a slight overhang at places and does not show any water seepage. Biogenic growth in the form of moss and small plants is seen in the middle zone.

The crown as well as the floor of the verandah has been plastered. On either side of the verandah there are cells. The cell on the right side has almost entirely perished. Some carvings on the sidewall suggest the presence of the cell. The cell on the left side is better preserved and the floor and sidewalls have undergone repairs. The cave has a single entrance and two huge windows flanking the door in the center. The lower part of the entrance and windows have been repaired. The rock above the entrance is fractured (Category II fracture). The wall of the front aisle and sides of the window recess have carvings. A part of this has been cemented. The top of the left window recess is uneven as it has been excavated along a unit contact.

The front, left and right aisles are a step lower than the central hall and the back aisle. On the sides are two galleries that are supported by four

pillars each. Both galleries are at a height of 1.30 m from the aisles. The walls of the galleries are ornamented with images of Buddha in teaching posture. The crown of the left gallery shows one category III fracture and a few category I fractures. 2-3 thin quartz/ zeolite veins are also present. In the right gallery, there are a few grade I & II fractures. Between the first and second pillars, quartz / zeolite veins have opened up a small cavity (Category V).

To the left of the shrine, the left aisle leads to a porch and cell, at a height of 1.20 m that can be approached by a flight of five steps. There are a few minor (category I) fractures in the porch while there are no fractures in the cell. To the right of the shrine, the right aisle leads to a porch and cell. These are also at a height of 1.20 m above the aisle.

In the front aisle, right aisle & left aisles, cracks falling in categories I to III are present (Plate VII – 53). The back aisle which is a step higher than the other aisles shows some fractures on the crown. These fall in category I to III.

There is no antechamber and the back aisle opens directly into the shrine that is adorned with the image of Buddha in teaching posture.

The central hall which is square in shape shows roopy structure, trace of unit contact, quartz / zeolite vugs at one or two places. The crown of the cave is supported by 12 pillars. The pillars have square bases, which become circular near the top.

Water seepage in cave 2 is seen in the front aisle at the contact of the wall & crown through a crack above the window (Plate VII – 53). The



water seepage is in the form of droplets.

Grade II weathering is seen on the west facing wall and sculptures. Grade I weathering is seen inside the cave. Grade II weathering is seen along unit contact near the floor. The rock outside the cave shows Grade III weathering.

Treatment suggested is as follows:

- 1) Reinforced shotcrete with rock bolts above cave 1 & 2 and selective shotcrete near the top of edge. Provision of windows and drainage at places.
- 2) Scraping of the top surface to expose fresh rock up to an area of 20m from the edge, followed by shotcreting the surface. Stripping of soil in this zone followed by laying of an impervious layer (geosynthetic or shotcrete) and later followed by relaying of the stripped soil with grass cover will adequately take care of the water seepage. A drain embedded in bedrock should be constructed at the upper end of the shotcreted zone.
- 3) Polymer filling of the cavity in the right gallery.

The geological log of the crown of cave 2 is presented in plate VII – 49 and section along the centerline is presented in plate VII - 50.

CAVE - 3

Cave 3 is a 'vihara', the outer portion of which, consisting of a wide verandah with pillars, at the same level as the floor of the cave, and extending to a lower floor, has been destroyed. Nothing of the external structure now exists, except a few bases of pillars. A part of the front wall, on the right side of the entrance along with a portion of the crown has perished (Plate VII – 53). A large block

(3m * 2m * 1.5m) forming a portion of the crown of the front aisle has collapsed. Beyond the verandah, remnants of ancient steps with some cell like excavations on either side can be seen.

Above the cave an overhanging portion has developed and some portions of the overhang have been dislodged. The rock above the cave appears to be extensively weathered.

On each side of the verandah there were two cells, of which only the one on the left is preserved. A cistern for water now exists on the right.

Cave 3 consists of four aisles, a central hall and 12 cells, five on either side and one each on either side of the shrine. The first cell on the right has perished almost entirely.

A portion of the crown of the front aisle has collapsed. There are category I fractures and trace of joints on the crown. Most of them appear to be crudely developed cooling joints.

On the left of the entrance the front wall contains a window that has been plastered and two pillars have been constructed for support. The wall above the window has developed a crack, which can be traced on the crown of the front aisle only for a small distance. On the left aisle there are category II & III cracks. A portion of the crown of the aisle has been plastered. The back aisle also has numerous cracks, some of which are probably cooling cracks.

The central hall also shows cooling joints on the crown. One major crack runs across the third cell on right, the right aisle, the beam on the right, the central hall, the left beam and the left aisle (Plate VII – 53). Within the cave the crack is wider towards south and narrower towards the north. There are no fractures in the shrine.

PORCH

SHRINE

PORCH



INDEX

SLIGHTLY WEATHERED VESICULAR BASALT

TRACE OF CRACKS/ FRACTURES

WATER SEEPAGE ZONES

HAZARD GRADATION OF CRACKS

CATEGORY I STABLE, HAIRLINE

CATEGORY II

CATEGORY III

CATEGORY IV

CATEGORY V UNSTABLE AREAS WHERE TREATMENT IS REQUIRED

R. L. OF FLOOR:622.91m

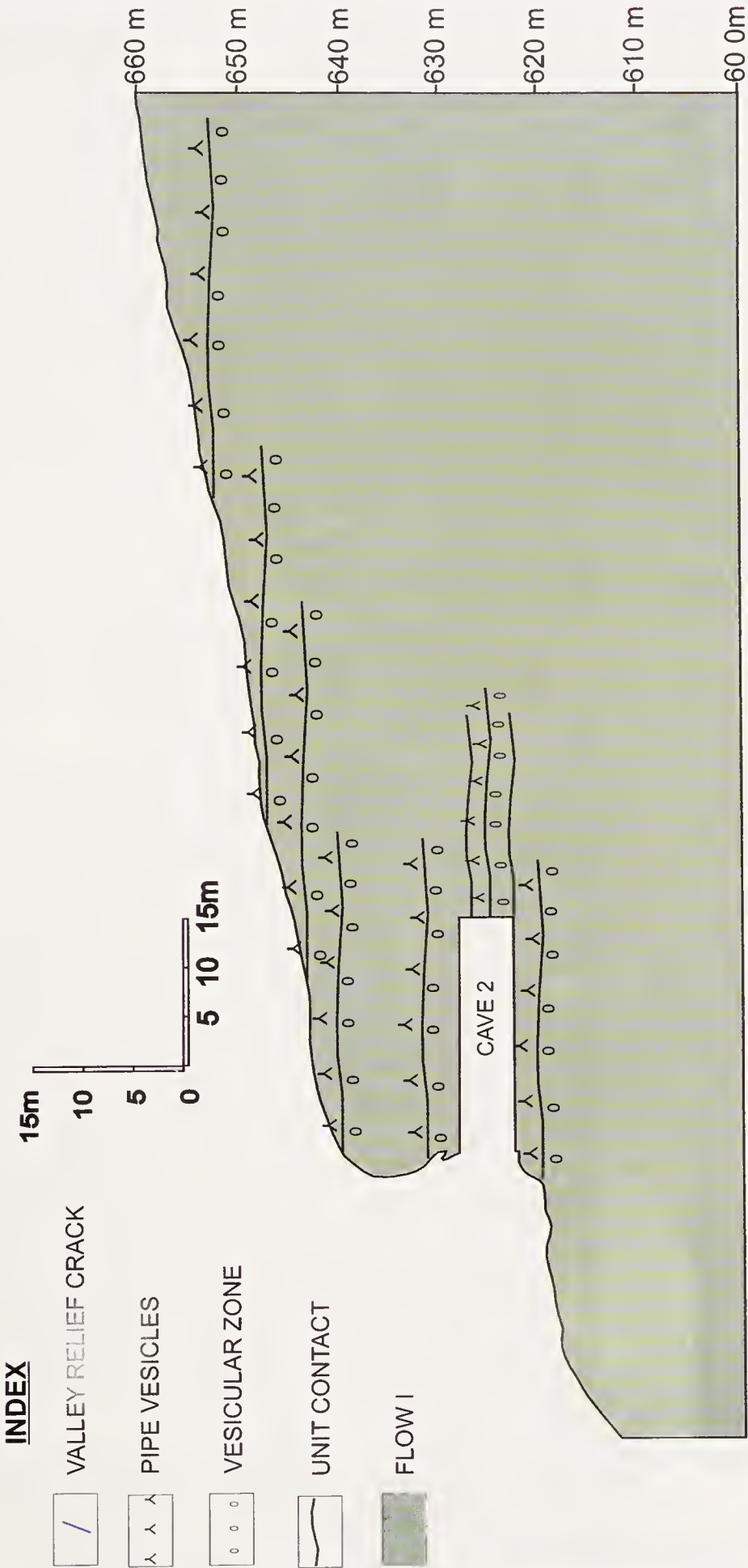
R. L. OF CROWN:627.66m

SHEETS:1

MAPPED BY: Dr. C. Joshi
Geologist Jr.

Plate : VII-50

GEOLOGICAL CROSS SECTION ALONG THE CENTRE LINE OF CAVE 2 AT ELLORA



Unit contact is seen at two levels on all walls of the cave, at heights of 0.35m & 2.25m from the floor. Pipe amygdules are present above the contact. Most of the pillars are reconstructed.

There is no water seepage inside the cave. Some water seepage is seen in the form of droplets from the façade. The water appears along a unit contact.

The water channel made above the cave and running from cave 5 towards and up to cave 1 appears to contribute to the water seepage.

The central hall of cave 3 is supported by 12 pillars, which have square bases, and show some carvings. Bracket capitals are present. All the pillars appear to be weathered and have been renovated. The weathering has been more in the lower portion of the cave. The floor has been re-plastered. The crack seen in the left aisle, hall, right aisle and cell appears to be more opened up towards the right side (south). This crack is along primary cooling joints and has opened up. The opening is 1-2 mm. The crack follows an irregular path and appears to be sub-vertical.

In the outer 6.5 m all structures like verandah, etc. have been completely destroyed. The outer right sidewall has perished. One block 3m x 2m x 1.5m on the crown of front aisle has collapsed.

The rock outside the cave shows grade III of weathering while inside the cave, the crown shows grade II and the walls show Grade II to III of weathering. The sculptures have lost detail. On the left wall the sculptures have been left unfinished after initial carving. Damage to sculptures on the back wall is due to weathering. Discoloration of rock due to bats is visible at many places.

The treatment suggested is as follows:

- 1) Reinforced shotcrete with rock bolts above cave 3 and selective shotcrete near the top

of edge. Provision of windows and drainage at places.

- 2) Scraping of the top surface to expose fresh rock up to an area of 20m from the edge, followed by shotcreting the surface. Stripping of soil in this zone followed by laying of an impervious layer (geosynthetic or shotcrete) and later followed by relaying of the stripped soil with grass cover will adequately take care of the water seepage. A drain embedded in bedrock should be constructed at the upper end of the shotcreted zone.

The geological log of the crown of cave 3 is presented in plate VII – 51 and section along the centerline is presented in plate VII - 52.

CAVE - 4

The outer 6 – 6.5m of the cave, which is a two-decked cave, has collapsed. The original cave must have consisted of an outer verandah, a central hall, an outer chamber and shrine on the lower deck facing west. On the upper deck, the cave probably consisted of a verandah, an antechamber, a shrine with walkaway and cells on either extremity.

Only a part of the hall, outer chamber and shrine on the lower deck and a small part of the verandah and outer chamber, half of the shrine and the cell on the eastern sides and part of the walkway remain now (Plate VII – 57).

Two pillars on the back aisle have survived. The bases of both pillars have been recast in cement. The floor of the hall is also cemented.

There are numerous cracks on the crown of the lower deck. The roof of the lower deck is about 90 – 95 cm thick. The cracks developed in the walls of the upper deck were repaired by insertion

GEOLOGICAL LOG OF CROWN OF CAVE 3 AT ELLORA

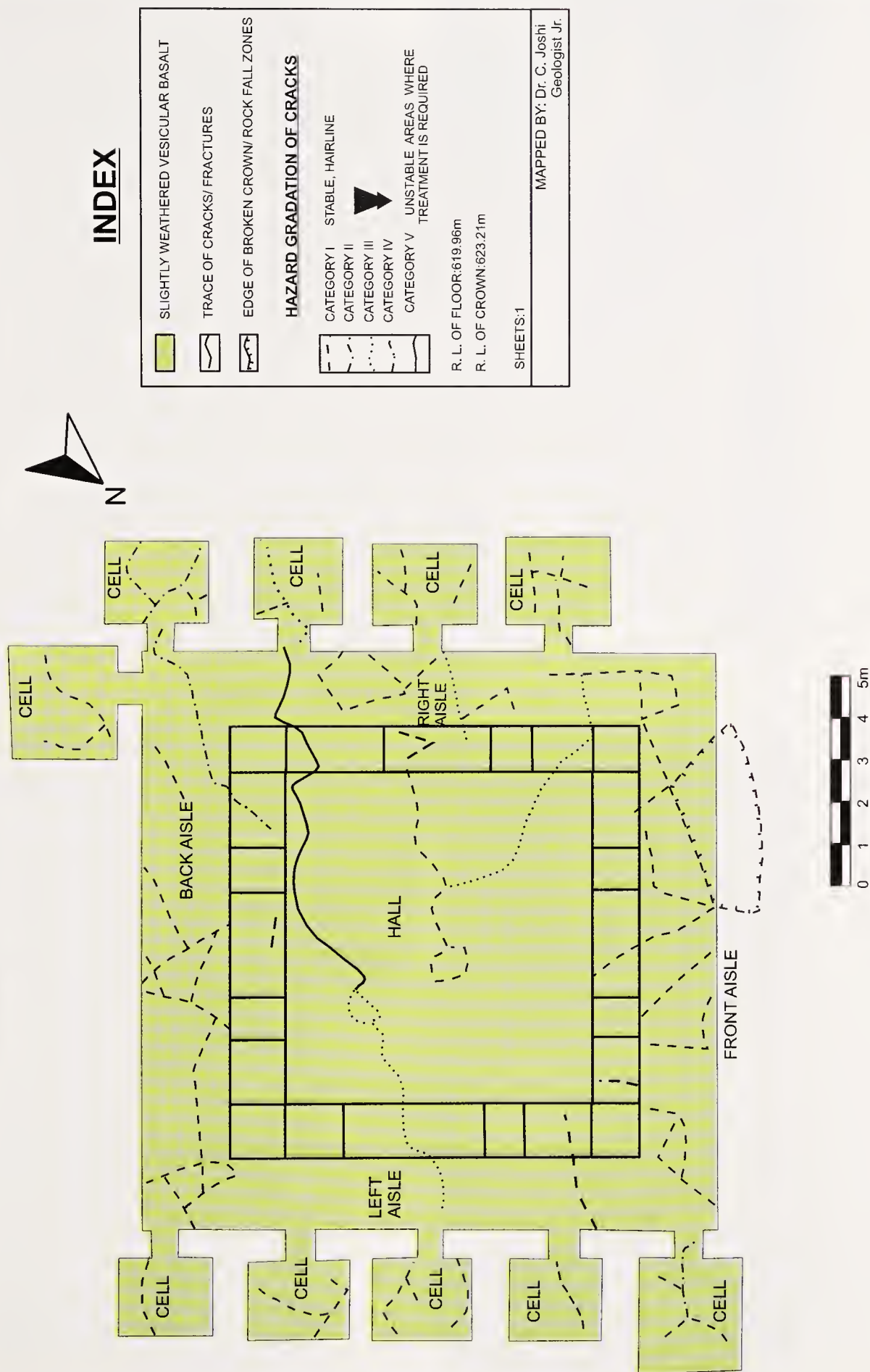
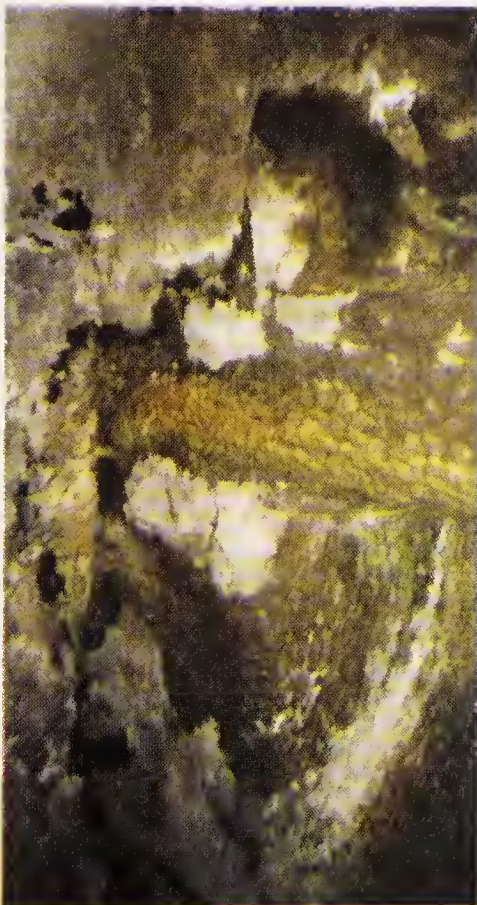


Plate : VII-52

GEOLOGICAL CROSS SECTION ALONG THE CENTRE LINE OF CAVE 3 AT ELLORA



Plate : VII-53



SEEPAGE - FRONT AISLE CAVE 2



CRACK ON CROWN OF FRONT AISLE - CAVE 2



CRACK ON CROWN OF HALL - CAVE 3



BROKEN FACADE OF CAVE 3



of clamps and grouting with cement mortar. Similarly the floor of the upper deck was extended by about 1-3m using RCC.

This additional load has resulted in the development of cracks in the walls of the shrine and the doorway of the walkway and in the walls of the cell on the eastern side (Plate VII – 57). Water seepage from the façade is through the weathered basalt (showing exfoliation weathering) in the form of droplets. There is no water seepage on the lower deck. Water seepage on the upper deck is through the weathered zone/ unit contact and is in the form of droplets.

The rock inside the shrine and back aisle is unweathered and fresh (Grade I). Along the unit contact weathering is accentuated (Grade-II). Grade-III weathering is seen outside the cave and in the partially excavated cells on the left side.

The cracks on the crown of the lower deck are probably primary with later opening up. The cracks are generally not seen on the floor of the upper deck and are probably concealed.

Sculptures show damages like loss of sharpness and detail due to weathering on lower deck while on upper deck the damages are due to collapse of outer sections.

On the facade an overhang has been created. In the overhanging portion a few blocks have started to dislodge.

The treatment suggested is as follows:

- 1) Reinforced shotcrete with rock bolts above cave 4 and selective shotcrete near the top of edge. Provision of windows and drainage at places.
- 2) Scraping of the top surface to expose fresh rock up to an area of 20m from the edge,

followed by shotcreting the surface. Stripping of soil in this zone followed by laying of an impervious layer (geosynthetic or shotcrete) and later followed by relaying of the stripped soil with grass cover will adequately take care of the water seepage. A drain embedded in bedrock should be constructed at the upper end of the shotcreted zone.

- 3) Two pillars and a beam may have to be constructed on the lower deck to check toppling failure.

The geological log of the crown of cave 4 is presented in plates VII – 54 & 55 and section along the centerline is presented in plate VII - 56.

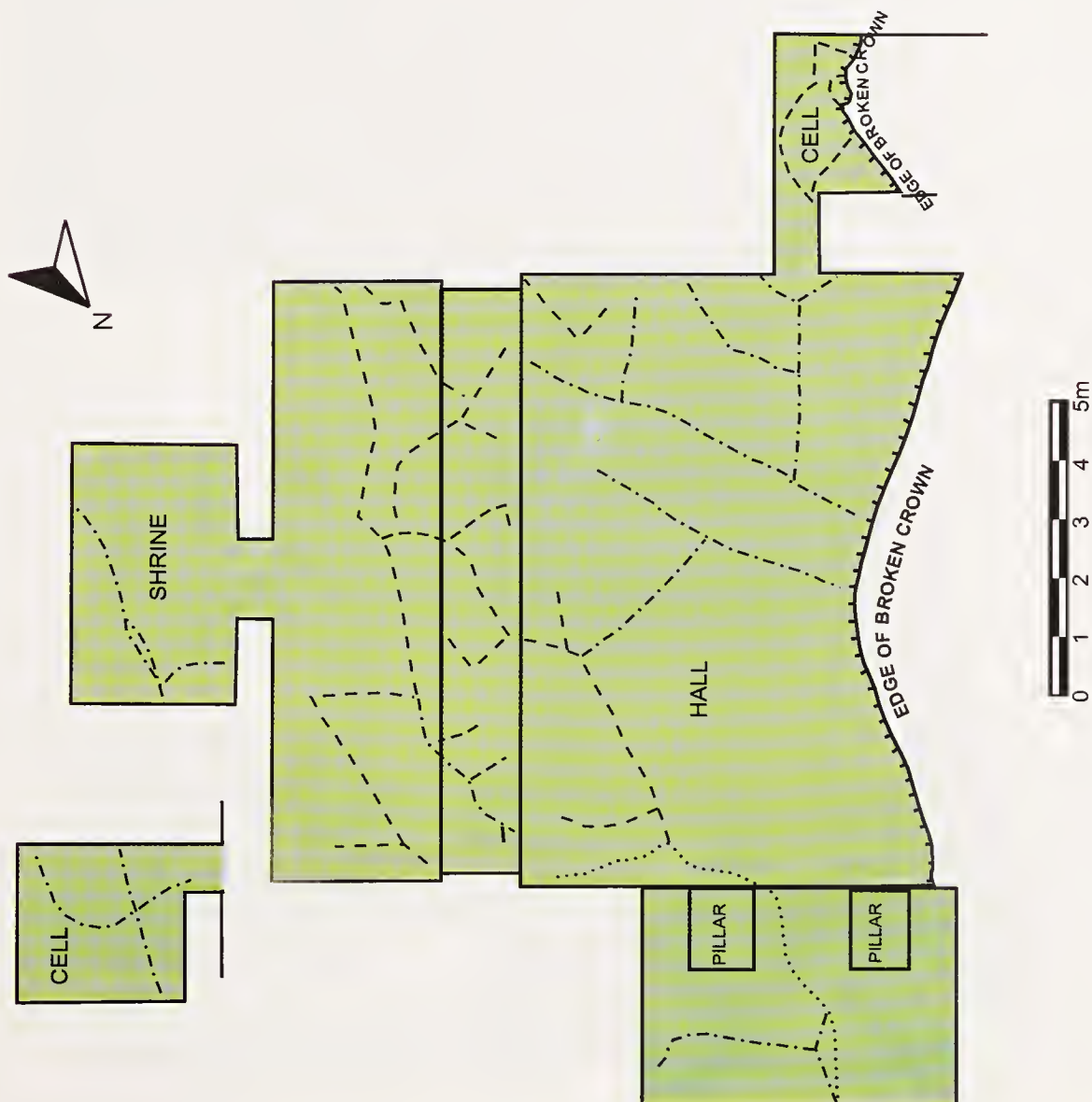
CAVE - 5

Cave 5 is a large cave and the surviving portion includes a central hall, back aisle, shrine and pillared porches with inner cells on either aisle. The destroyed portion must have included the front aisle, an outer verandah. Above this cave is a stream that flows only for a part of the year. The flow of water has been regulated with the construction of a cantilever limb. In the scarp below the cave, remnants of a staircase can be seen descending to the nala floor. The outer 7-8m of the cave has been destroyed.

In the front aisle the crown has partially collapsed. Three of four pillars on the front side have been recast in cement. Bases of all the pillars in the hall have been renovated/ restored using cement. On each end of the front aisle is a cell. The cell on the right has perished. The cell on the left is intact.

In the first cell on the right aisle, which is at a slightly higher level, unit contact is seen at a height of about 1.2 - 1.5 m from the base. At the entrance to this cell the left wall is fractured. In the second

GEOLOGICAL LOG OF CROWN OF LOWER DECK CAVE 4 AT ELLORA

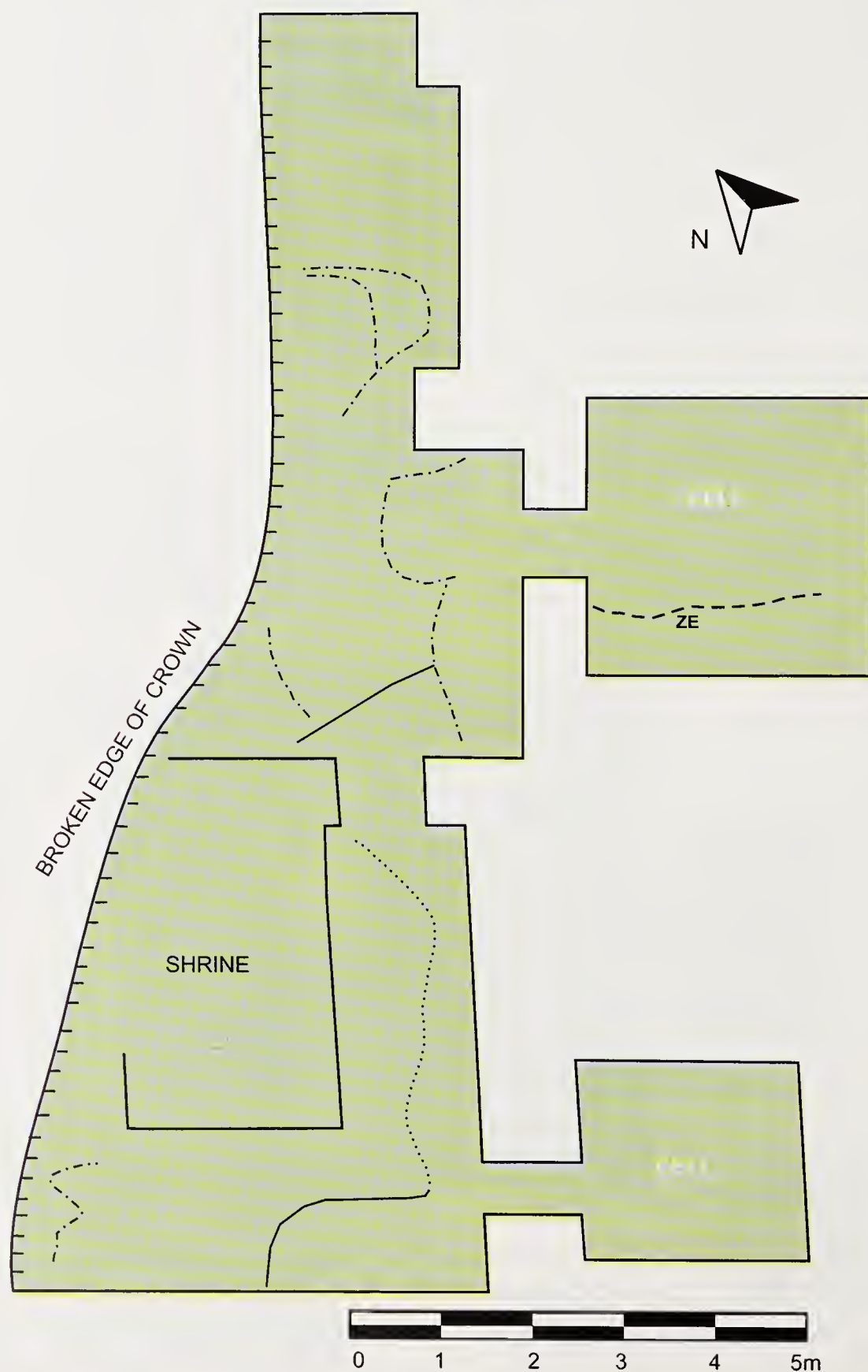


INDEX

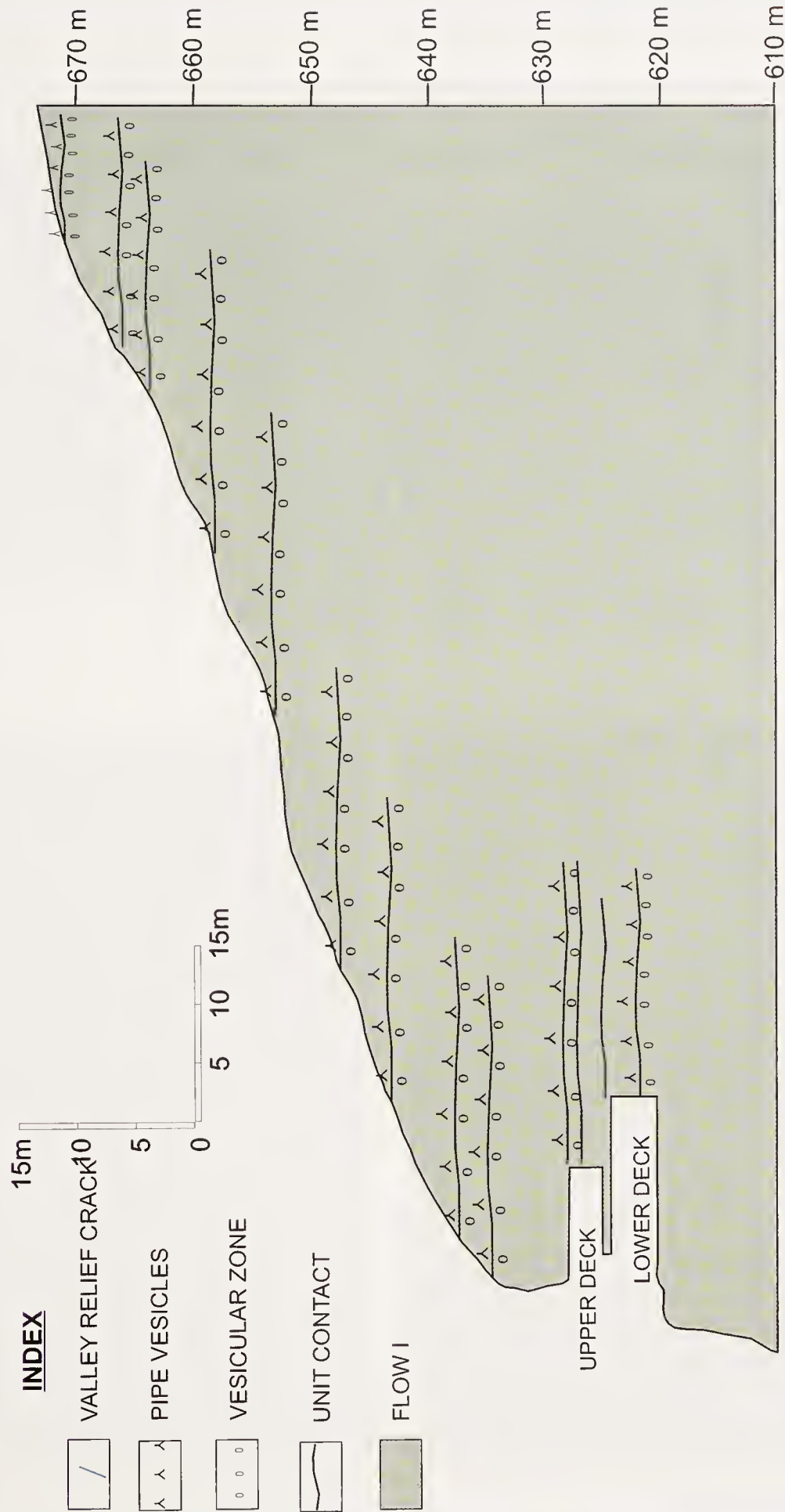
	SLIGHTLY WEATHERED VESICULAR BASALT
	TRACE OF UNIT CONTACT / SQUEEZE UPS
	TRACE OF CRACKS/ FRACTURES
	WATER SEEPAGE ZONES
	EDGE OF BROKEN CROWN/ ROCK FALL ZONES
HAZARD GRADATION OF CRACKS	
	CATEGORY I STABLE, HAIRLINE
	CATEGORY II
	CATEGORY III
	CATEGORY IV
	CATEGORY V UNSTABLE AREAS WHERE TREATMENT IS REQUIRED
UPPER DECK	
R. L. OF FLOOR: 624.60m	
R. L. OF CROWN: 627.60m	
LOWER DECK	
R. L. OF FLOOR: 620.30m	
R. L. OF CROWN: 623.40m	
SHEETS: 2	
MAPPED BY: Dr. C. Joshi Geologist Jr.	



**GEOLOGICAL LOG OF CROWN OF UPPER DECK OF
CAVE 4 AT ELLORA**

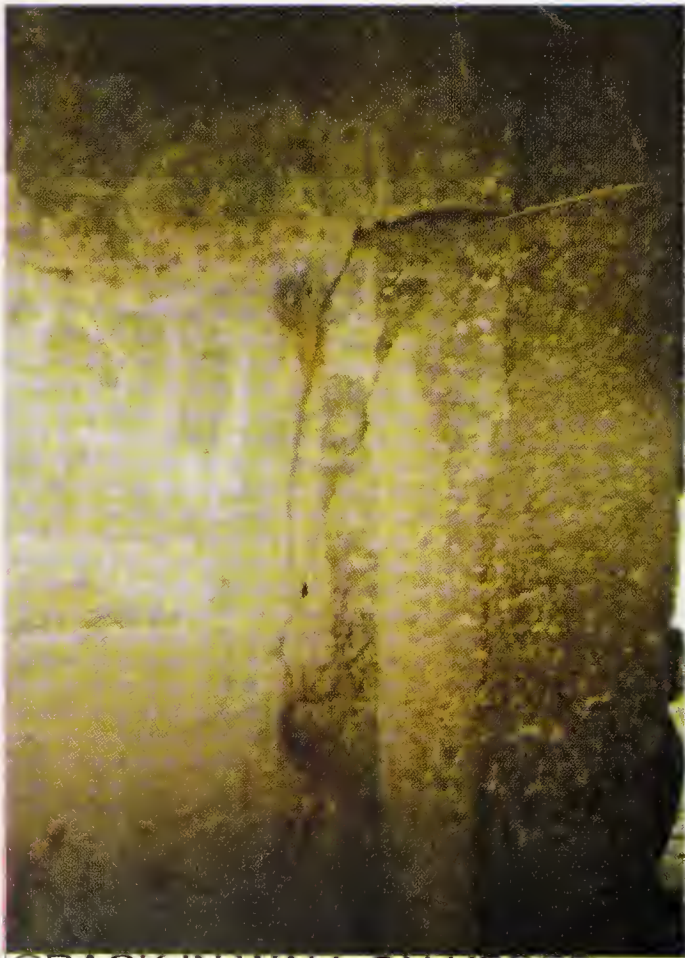


GEOLOGICAL CROSS SECTION ALONG THE CENTRE LINE OF CAVE 4 AT ELLORA





OVERHANG CREATED IN FACADE OF CAVES 1- 5



CRACK IN WALL ON UPPER DECK OF CAVE 4



CRACK DEVELOPED DUE TO OVERLOADING OF FLOOR - UPPER DECK OF CAVE 4



cell unit contact is not visible. Minor category fractures are seen.

The lower half of the left wall of the front aisle has been cement plastered. Unit contact can be seen at a height of 2.4 – 2.7 m. The floor of the cell has been excavated below the level at the verandah floor and has been left uneven. There are no fractures on the crown or walls of this cell.

On the left aisle there is a pillared porch and shrine. Both the pillars of the porch have collapsed. Only the brackets and bases survive. The porch & cells are at a height of 85 – 90 cm from the floor of the left aisle. The entrance to the shrine is cemented. Trace of squeeze up structure and a few small zeolite veins can be seen on the crown of the porch. The shrine is small in size and top corner of the left wall is 90 cm deep.

Next on the left aisle is cell. Unit contact is visible inside the cell.

Towards the middle of the left aisle is a complex of a large pillared porch with four completed cells. At one place excavation to a cell has been left incomplete. On the crown is a large zeolite vug. Beyond this complex are two more cells.

In the cell, situated on the left of the porch of the left aisle, trace of unit contact is seen on the crown. No fractures are present. On the second cell on the right wall trace of unit contact is seen on the crown. No fractures are present.

In the cell on the back wall minor category I

fracture is present. In the 2nd cell on the right wall, trace of unit contact is seen. One vug filled with quartz crystals is present on the crown. In the first cell on the right wall a big vug with zeolite crystals can be seen. There are no cracks.

Beyond the porch on the left aisle, there are two cells. While there are no fractures in the first cell, minor fractures are seen in the second cell. The back aisle opens into a cell on either side. No fractures are present in the cells.

Weathering: Outer façade and floor show grade II weathering while the rock inside the cave is fresh. Damage to sculptures is not generally noticed. In the first shrine on left of hall, damage to sculpture is due to presence of a joint. No seepage is noticed inside the cave.

The treatment suggested is as follows:

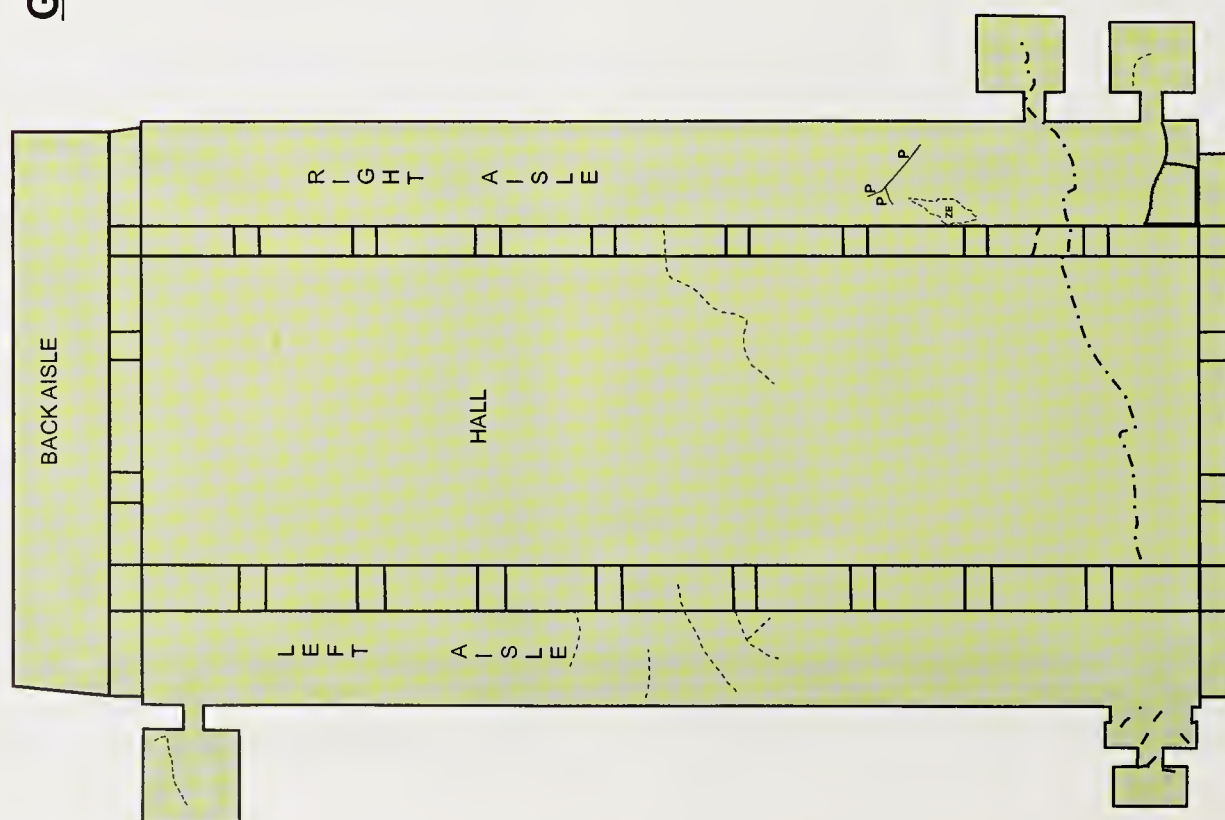
- 1) Filling up of potholes and pools up to the waterfall in the major nala above cave 5.
- 2) Lining of the central 5 m of the nala channel over which perennial flow is observed.
- 3) Provision of an iron barrier 20m from the edge to catch rolling boulders.
- 4) Reinforced shotcrete with galvanised wire below cave.

The geological log of the crown of cave 5 is presented in plates VII – 58 & 59 and section along the centerline is presented in plate VII - 60.

Plate : VII-58

GEOLOGICAL LOG OF CROWN OF CAVE 5 AT ELLORA

SHEET - I



INDEX

-  SLIGHTLY WEATHERED VESICULAR BASALT
-  TRACE OF UNIT CONTACT / SQUEEZE UPS
-  TRACE OF CRACKS/ FRACTURES
-  PLASTERED CRACKS
-  EDGE OF BROKEN CROWN/ ROCK FALL ZONES

HAZARD GRADATION OF CRACKS

-  CATEGORY I STABLE, HAIRLINE
-  CATEGORY II
-  CATEGORY III
-  CATEGORY IV
-  CATEGORY V UNSTABLE AREAS WHERE TREATMENT IS REQUIRED

R. L. OF FLOOR: 623.75m

R. L. OF CROWN: 628.55m

SHEETS: 2

MAPPED BY: Dr. C. Joshi
Geologist Jr.

Plate : VII-59

GEOLOGICAL LOG OF CROWN OF CAVE 5 AT ELLORA

PILLARED PORCH & CELL ON LEFT AISLE **SHEET - II** PILLARED PORCH & CELLS ON RIGHT AISLE

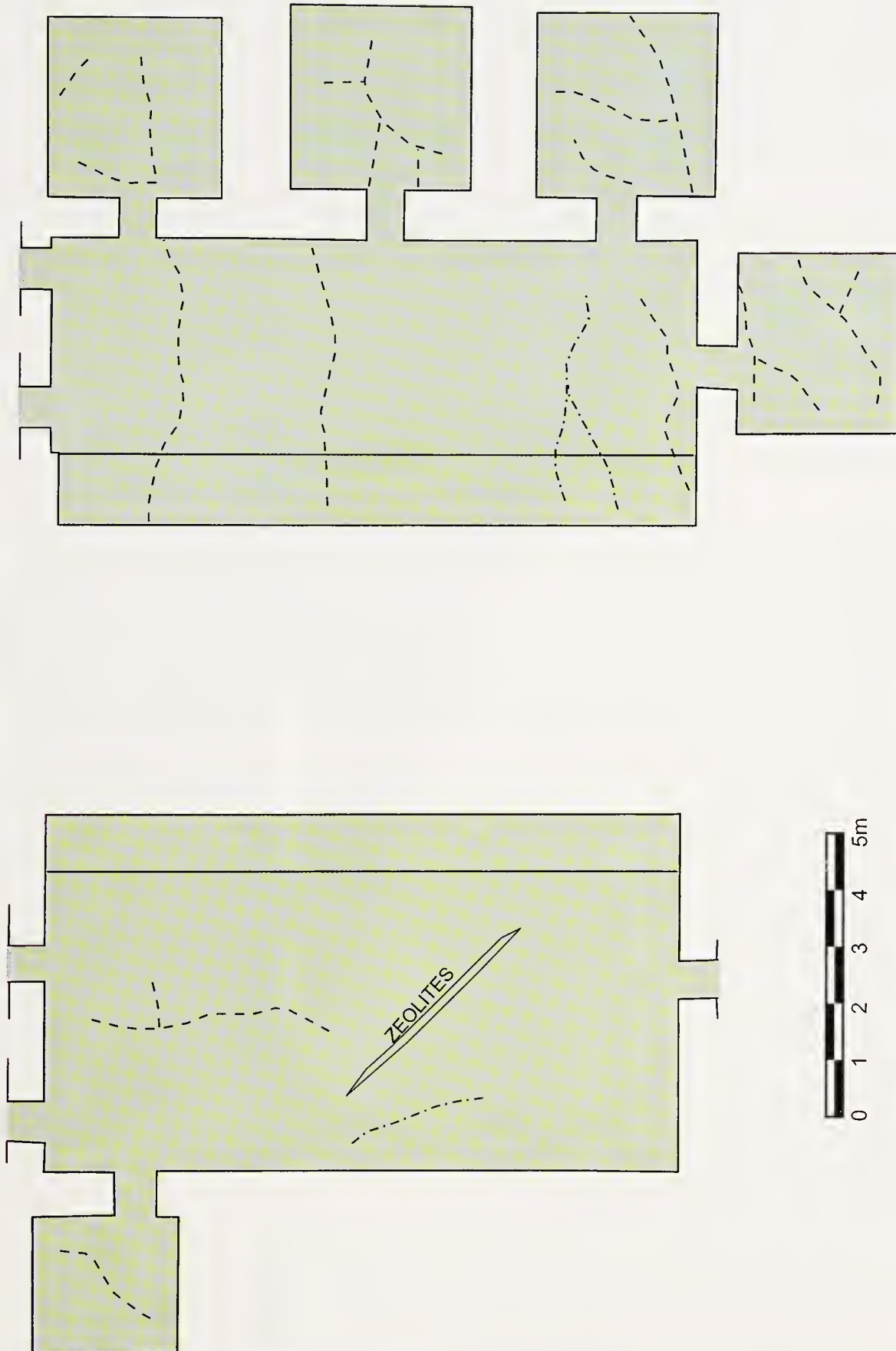
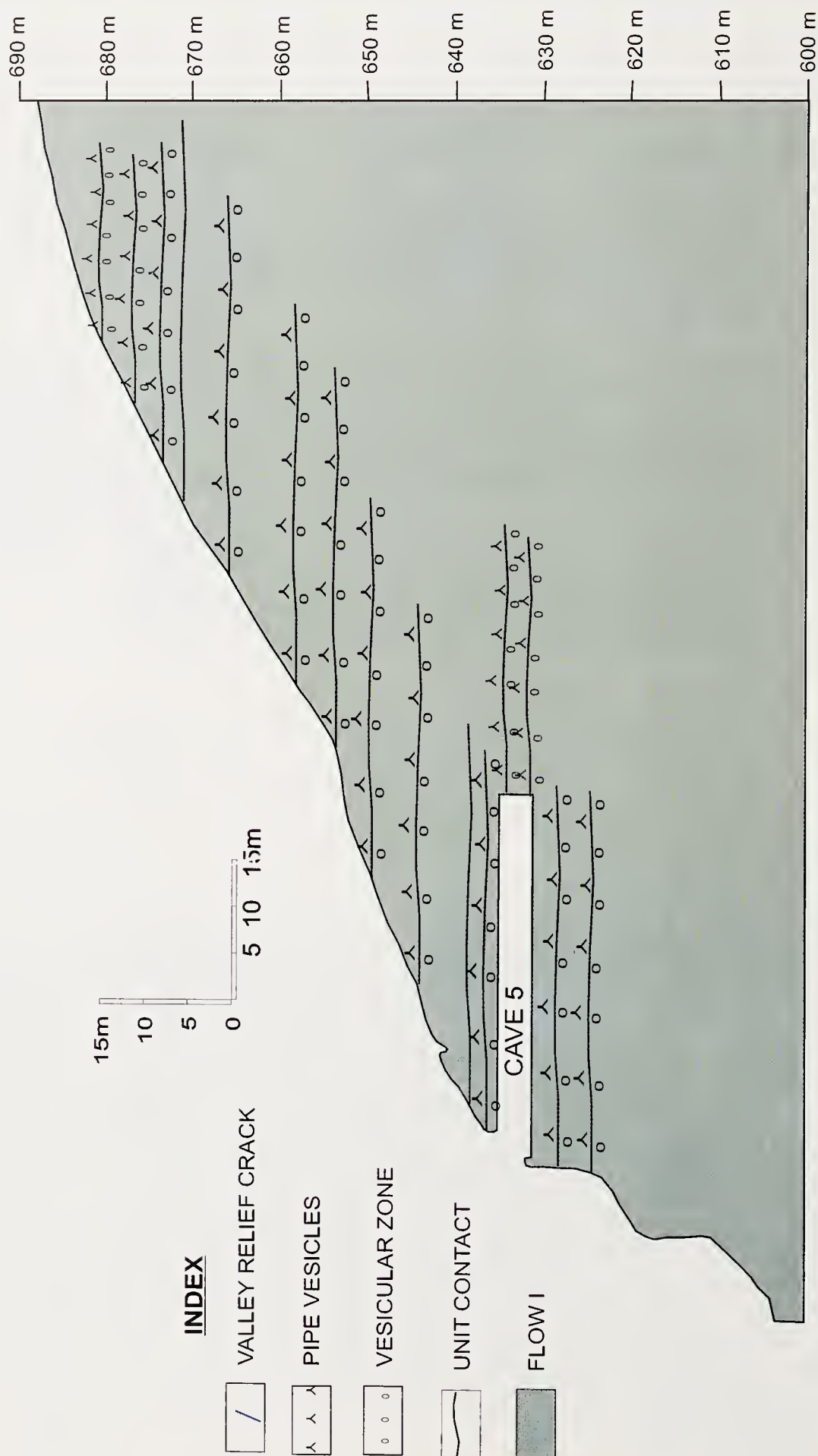


Plate : VII-60

GEOLOGICAL CROSS SECTION ALONG THE CENTRE LINE OF CAVE 5 AT ELLORA



CAVE – 6

Cave 6 is approached by a flight of steps from the lower level where caves 7 & 8 are situated. The outer 3-4m of cave has collapsed. The collapsed portions may have included one cell and verandah on the outer right side of cave 6. Cave 6 is different in architecture from other caves. It consists of a central hall, which leads to an antechamber and shrine. On the sides of the central hall are two side halls. At least two pillars, which were supporting the crown at the outermost extremity, have collapsed. The hall on the right has three completed and one incomplete cell. The outer wall of the right hall and part of the crown has collapsed at two different levels along two unit contacts. Casts of ropy structure can be seen on both surfaces where roof collapse has taken place (Plate VII – 63).

On the walls of the right hall, unit contact can be seen. Pipe amygdules are also visible. Apart from the horizontal cracks along the unit contact a few vertical cracks can also be seen.

The crown of the central hall which is higher than the two side halls shows trace of unit contact and a few category V fractures (Plate VII – 63). The outer wall and part of the crown have perished. The left wall shows traces of unit contact on the crown. The lower unit contact cannot be clearly deciphered. Two category III cracks can be seen on the crown. The left wall has 6 cells, two of which have minor fractures.

Towards the front, the left hall has two windows. Vertical cracks can be seen in the window recess and the trace can be seen on the walls. From the outside the trace of this crack can be seen on the wall (Plate VII – 63). This sub-vertical crack has the highest hazard potential (category V) and is being monitored using mechanical demag.

There is a verandah like structure outside the left hall of cave 6, which leads to cave 9. In the verandah Grade II cracks are seen on the crown. No fractures are seen in the antechambers and shrine.

The floor of cave 6 is about 6.30m above the level of the ground. The centerline of cave 6 falls on the centerline of cave 7. There is no water seepage in cave 6.

Weathering: Floor up to 8m shows Grade II of weathering. Inside the cave Grade I of weathering is seen. Sculptures show loss of sharpness due to weathering. Some breakage observed in sculptures is due to minor cracks.

A major zone of de-slaking has been created on the outer side due to pervasive discontinuity.

The treatment suggested is as follows:

- 1) Plain shotcrete and rock bolt above cave 6.
- 2) Construction of a suitable structure to provide support from below. This should be designed in consultation with a structural engineer.

The geological log of the crown of cave 6 is presented in plate VII – 61 and section along the centerline of cave 6 & 7 is presented in plate VII - 62.

CAVE - 7

Cave 7 is situated below cave 6 and the center lines of both caves fall on the same axis. Outside the hall there must have been an outer verandah, which has now perished. In the outer 3-5m all structures have collapsed.

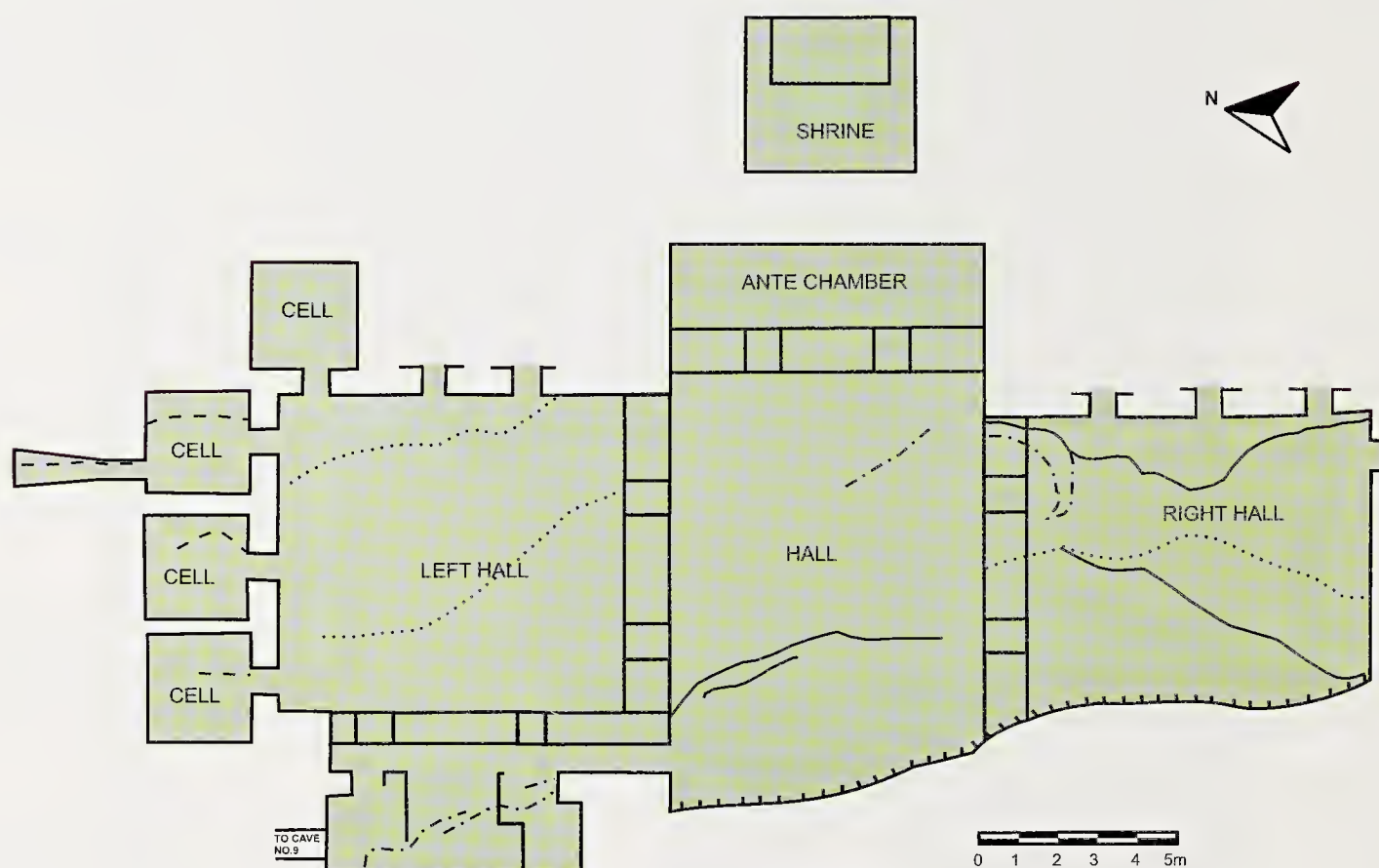
The cave consists of a huge square hall with cells on three sides. The crown is supported by four square pillars all of modern construction.

On the right wall of the hall are three cells. Unit contact is not very clearly seen. Inside the cells minor cracks are present.

A large portion of the crown to the right has fallen, along a unit contact. Casts of ropy structure are visible. The crown of the cave bears numerous cracks, some of which are along unit contacts.

There are five cells on the back wall, some of which are incomplete. On the back wall, unit contact can be deciphered at a height of 90 cm from the

GEOLOGICAL LOG OF CROWN OF CAVE 6 AT ELLORA



INDEX

	SLIGHTLY WEATHERED VESICULAR BASALT	<u>HAZARD GRADATION OF CRACKS</u>		
	TRACE OF CRACKS/ FRACTURES		CATEGORY I	STABLE, HAIRLINE
			CATEGORY II	
			CATEGORY III	
			CATEGORY IV	
			CATEGORY V	
	EDGE OF BROKEN CROWN/ ROCK FALL ZONES			
				UNSTABLE AREAS WHERE TREATMENT IS REQUIRED
R. L. OF FLOOR:624.65 m				
R. L. OF CROWN:628.55 m				
SHEETS: 1				
		MAPPED BY: Dr. C. Joshi Geologist Jr.		

Plate : VII-62

GEOLOGICAL CROSS SECTION ALONG THE CENTRE LINE OF CAVES 6 & 7 AT ELLORA

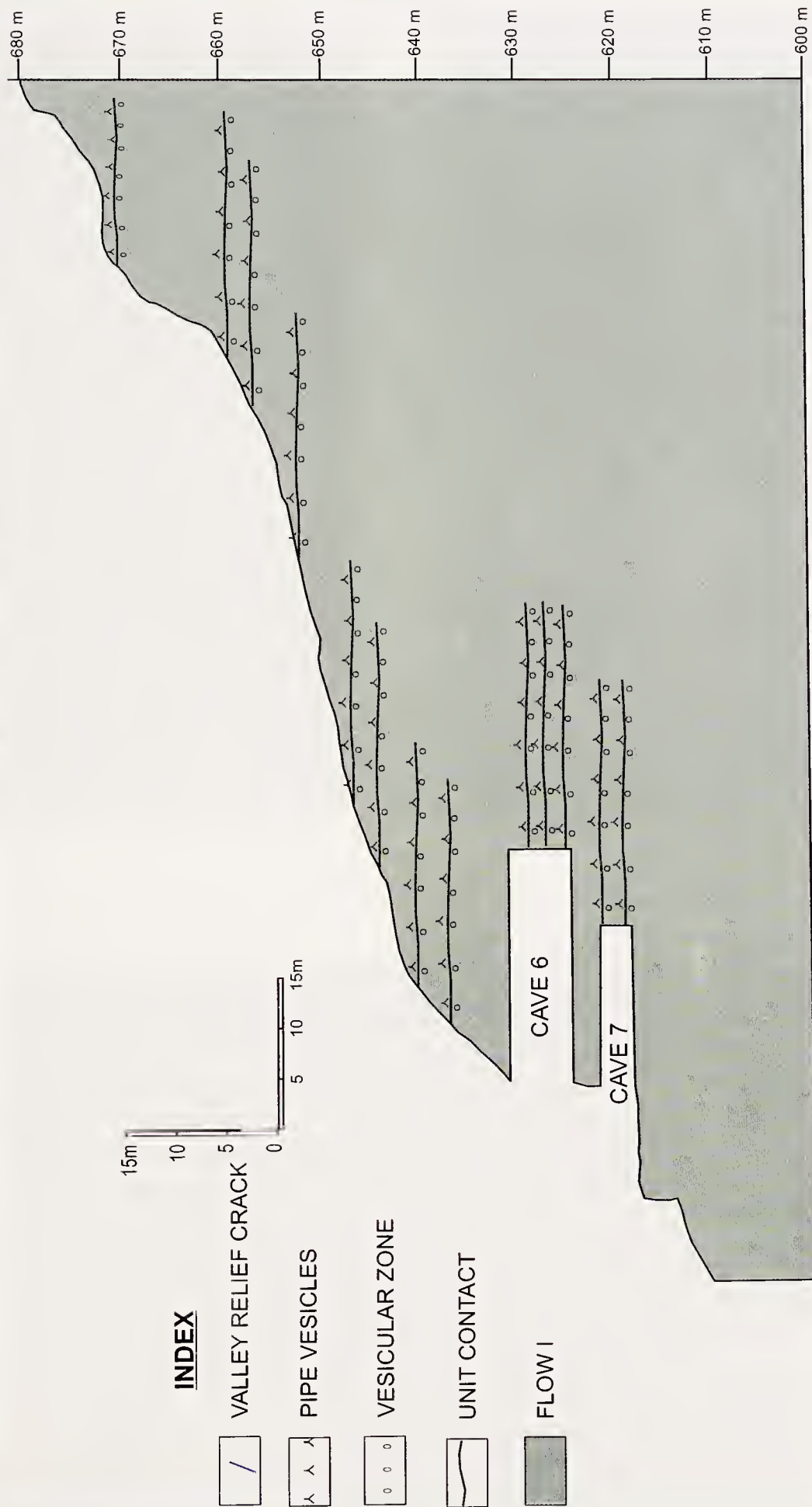
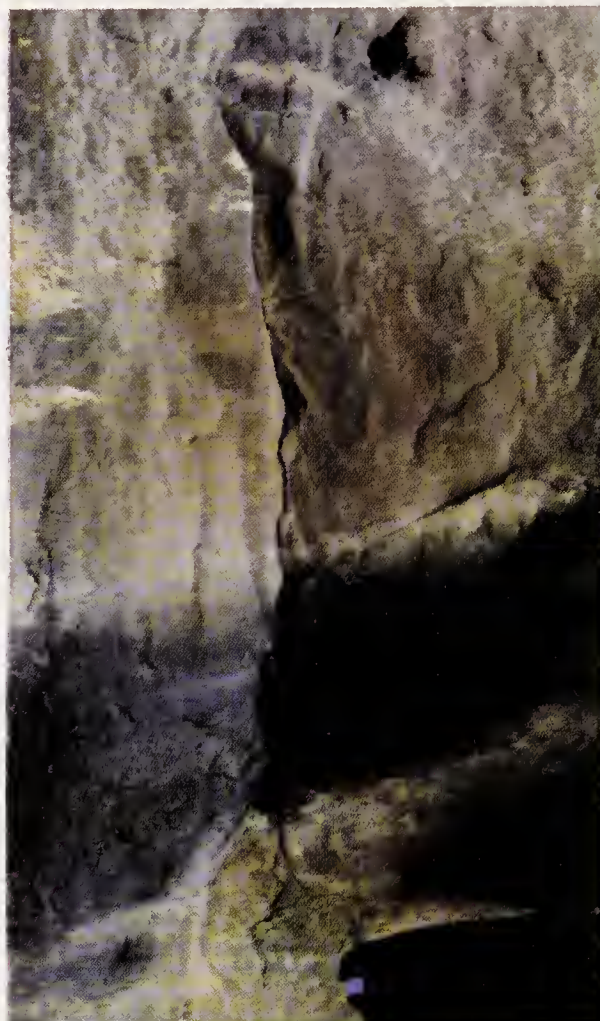


Plate : VII-63



CAST OF ROPY STRUCTURE ON CROWN OF CAVE 6



CRACK SEEN ON CROWN OF CAVE 6 CAN ALSO BE SEEN ON THE OUTER WALL - GIVING RISE TO UNSTABLE BLOCK



CRACK ON CROWN OF CAVE 6

floor. This can be traced on the left wall.

The left wall has openings to four cells one of which is open from both ends and leads to cave 8. On the left side of the cave there is a second entrance. Part of the left and right wall has been plastered.

Four pillars have been reconstructed to support the crown. The category V crack seen on the crown in the hall can be traced on the floor of left hall of cave 6 which is stacked above cave 7.

No water seepage is seen inside the cave. No sculptures are present except one to the right of the central cell. Grade II weathering is seen on the crown while the floor and rock outside the cave show grade III weathering.

The treatment suggested is as follows:

- 1) Shotcreting of the crown of the cave to arrest flaking.
- 2) Load test at the portal

The geological log of the crown of cave 7 is presented in plate VII – 64 and section along the centerline of caves 6 & 7 is presented in plate VII - 62.

CAVE - 8

Cave 8 is situated below cave 9 is a 'vihara', the shrine of which has a circum-ambulatory passage, the only one of its kind at Ellora.

It consists of an outer hall, the front portion of which has been left somewhat unfinished. Here, trace of unit contact, vugs with green chert as filling and zeolites can be seen. The crown of the outer hall is weathered and requires treatment at the outer extremity. A few grade III fractures are also present.

The outer hall has a shrine on the left wall that is

placed at a higher level than the floor of the hall. Below the shrine is a large cell like opening, which has now been covered. A minor crack is present on the crown of the cave.

The outer hall leads into an inner hall. The crown on the inner hall is without fractures. Only a quartz vein is seen. The inner hall has three cells on the left side. The third cell has a major crack on the crown and walls. This crack cannot be however traced on the wall of the hall. On the right wall of this hall there is a cell open from both ends and that leads to cave 7.

The inner hall leads into another hall, at the center of which is a shrine having a walkway surrounding it. On the left wall are three cells, which have only minor cracks.

At the back of the cave there is another rectangular hall, situated at a higher level. On the walls of the halls, unit contacts are not clearly visible except on the outer wall where it is observed at a height of 90 cm from the floor.

A vein filled with green chert is seen at about 3-4 m from the ground. The bottom portions of all the pillars have been plastered.

There is no water seepage in the cave. At the level of the floor up to 20 cm the base of sculptures have weathered along a unit contact. Grade-II weathering is seen on the floor. Grade I weathering is seen on the crown and walls.

Zone of de-slaking has been created due to displacement along a crack developed along a unit contact.

The treatment suggested is as follows:

1. Rock bolting to stabilise the de-slaking block.



The geological log of the crown of cave 8 is presented in plate VII – 65.

CAVE – 9

Cave 9 is a small cave situated at a higher level, above cave 8. It is now approached through cave 6 by a small porch with four pillars and a small passage.

Cave 9 consists of a small open courtyard, the façade of which is decorated with a chaitya motif. The right wall of the cave is cut into a vertical scarp. A part of the façade above the chaitya motif has been broken. The cave consists of a small rectangular verandah supported by two pillars. The back wall of the verandah is highly ornamented, with an image of Buddha in preaching posture in the center. The right wall of the verandah contains a doorway to a cell.

It is probable that cave 9 formed a part of a larger cave complex probably consisting of caves 6, 7, 8 & 9.

Unit contact is not seen on the walls. Three parallel horizontal quartz veins are observed. Inside the cell, trace of squeeze up structure can be seen on the crown.

In the outer part of the cave the rock is slightly weathered (Grade-II) while the interior of the cave is unweathered.

The treatment suggested is as follows:

1. Shotcrete of the façade to be extended up to 5 m from the top. The existing drain should be modified and should be extended down to bedrock level. A new drain above the existing drain may be necessary.

The geological log of the crown of cave 9 is presented in plate VII – 66.

CAVE - 10

Cave 10 is a 'Chaitya griha'. Its entrance is through a wall, which is in dilapidated condition. Inside is a square courtyard. The rock mass over the courtyard has been completely excavated rendering it open to sky (Plate VII – 71). On three sides of the courtyard are verandahs with porches & cells. The right wall of the courtyard is moderately to highly weathered and crumbled (flaking) at places.

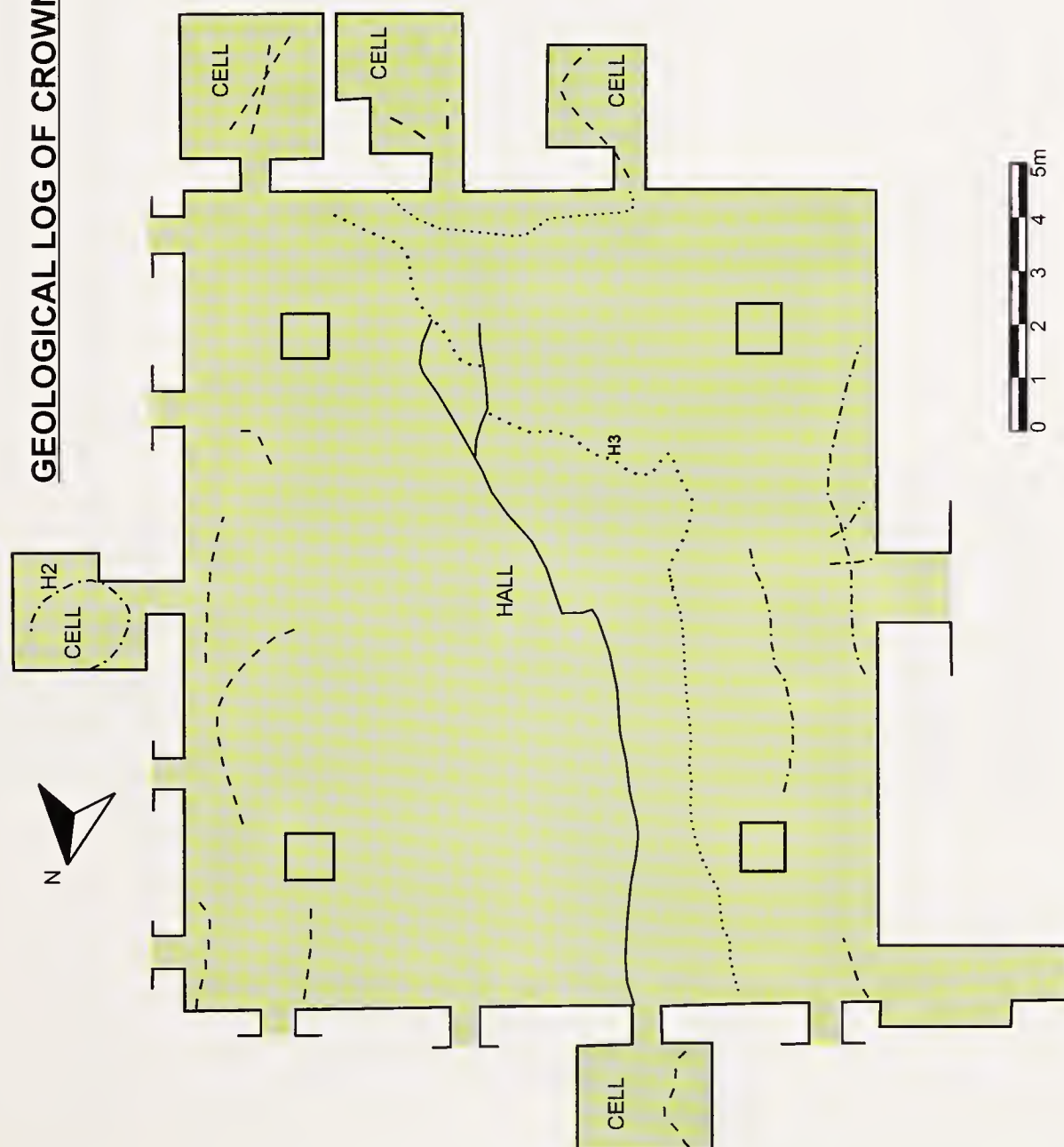
The façade of the cave is made up of a 'Chaitya' – opening on the upper deck. Above this is a small overhang decorated with rock cut beams & rafters in imitation of wooden architecture. The overhang is cut across by a westerly dipping crack and unit contact. Water seepage is observed at three places from the overhang in the form of droplets. Some of the rafters are damaged (Plate VII – 71).

The verandah lower deck of cave 10 is situated at a height of about 1.30m above the level of the courtyard. On the walls of the courtyard (below the verandah), Unit contact can be seen at about 30 cm from the base. Pipe amygdulites are present. The pipes are mostly filled with silica. At places green earth as filling can also be seen.

In the right verandah the outer wall (western) is highly weathered. The crown of the verandah is fractured at many places. Water seepage is reported through a few cracks. At places sub horizontal cracks have been observed. Some portions of the crown may collapse along these cracks. Inside the right verandah is a large cell the crown of which contains many fractures. Small portions of the crown have collapsed along a unit contact. Some seepage is reported in the cell.

In the right verandah the second unit contact can be seen at a height of approximately 3 m from the floor.

GEOLOGICAL LOG OF CROWN OF CAVE 7 AT ELLORA

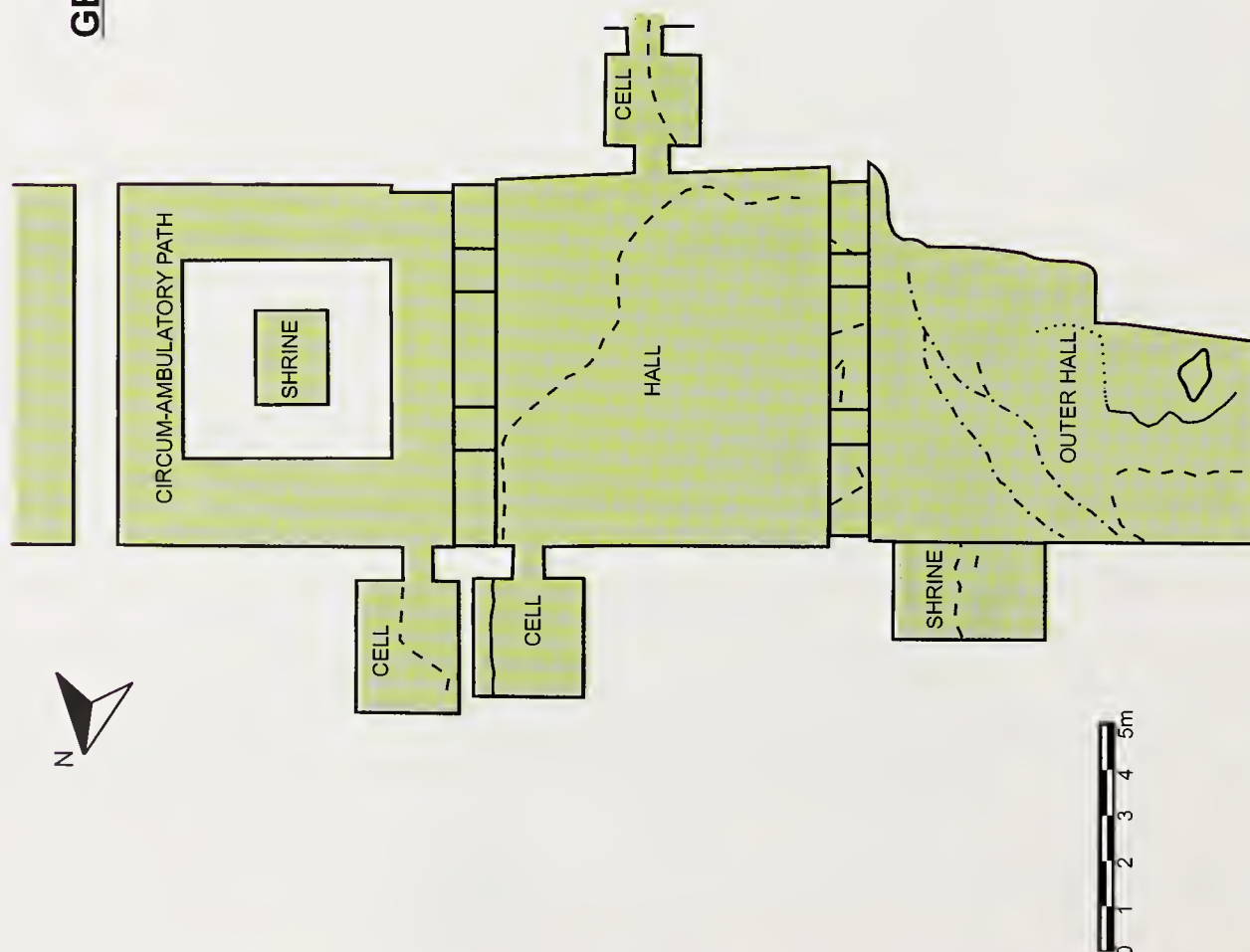


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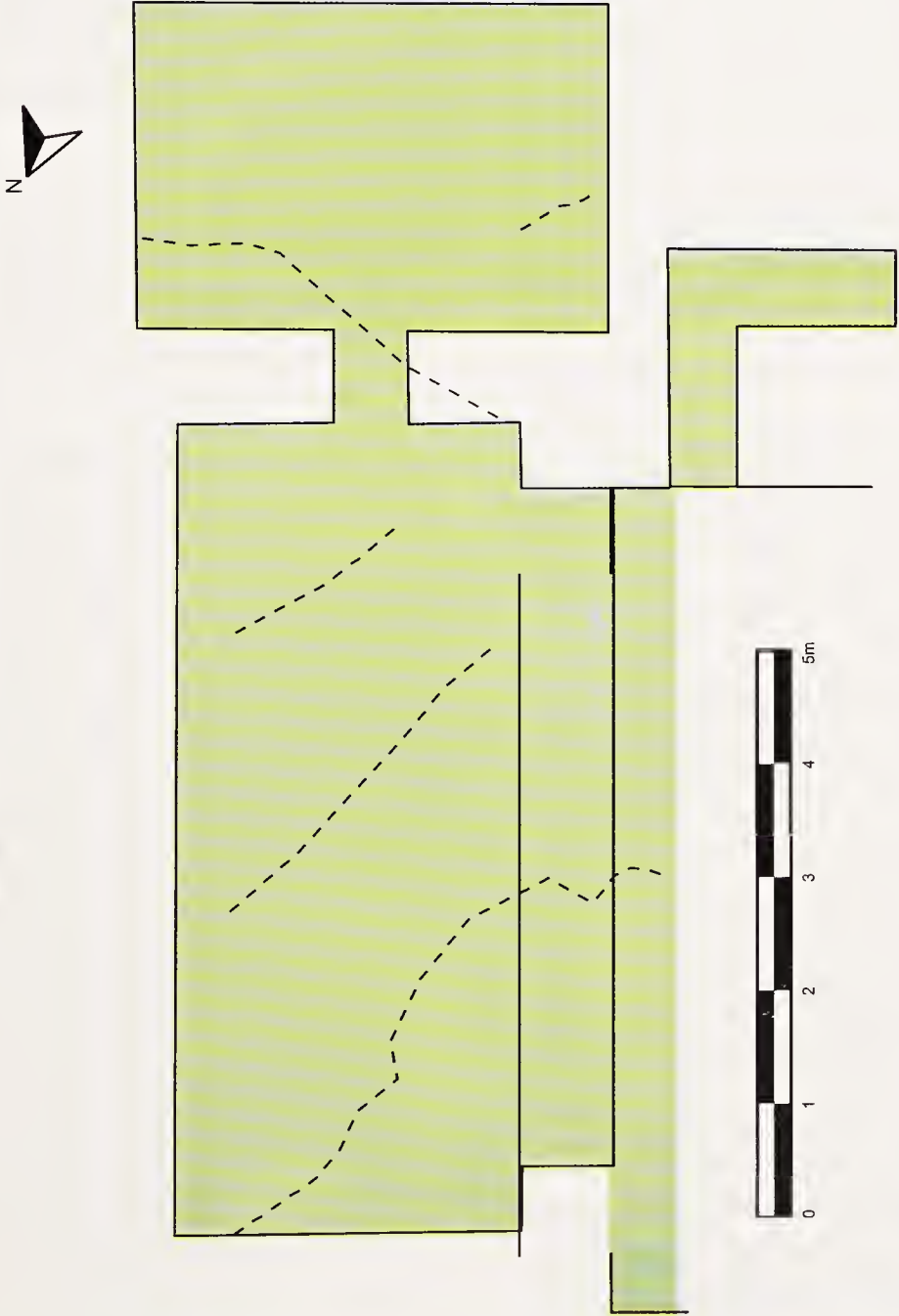
	SLIGHTLY WEATHERED VESICULAR BASALT
	TRACE OF CRACKS/ FRACTURES
	WATER SEEPAGE ZONES
HAZARD GRADATION OF CRACKS	
	GRADE I
	GRADE II
	GRADE III
	GRADE IV
	GRADE V
	STABLE; HAIRLINE
	UNSTABLE AREAS WHERE TREATMENT IS REQUIRED
R. L. OF FLOOR: 618.35 m	
R. L. OF CROWN: 621.45 m	
SHEETS: 1	
MAPPED BY: Dr. C. Joshi Geologist Jr.	

Plate : VII-65

GEOLOGICAL LOG OF CROWN OF CAVE 8 AT ELLORA



GEOLOGICAL LOG OF CROWN OF CAVE 9 AT ELLORA



INDEX

- SLIGHTLY WEATHERED VESICULAR BASALT
- TRACE OF CRACKS/ FRACTURES

HAZARD GRADATION OF CRACKS

- GRADE I
 - GRADE II
 - GRADE III
 - GRADE IV
 - GRADE V
- STABLE, HAIRLINE
- UNSTABLE AREAS WHERE TREATMENT IS REQUIRED

R. L. OF FLOOR: 623.25 m

SHEETS: 1

MAPPED BY: Dr. C. Joshi
Geologist Jr.

At the end of the right verandah is a small square verandah (at the junction with the front verandah). On the crown of this verandah is a fracture with calcitic encrustation on either side. The verandah on the right opens into a pillared porch with a shrine. Minor cracks can be seen on the crown of both porch & shrine. Another cell present on the remaining wall does not show any fractures.

The crown of the front verandah are divided into three sections by two beams. The section on the right is coated with a black oily (?) substance. Only minor cracks are present. A small portion of the overhang of the front verandah has fallen at one place. In the central portion, trace of unit contact is seen, along which weathering has taken place and a small gap has been created. A major fracture is also seen in the central section and has calcitic encrustations on either side. Unit contact is seen at a height of about 3 m on the walls of the verandah.

To the left of the front verandah (at the junction with the left verandah) is a small square verandah. On the crown, trace of a squeeze up structure can be seen. On the left is a pillared porch with partially excavated cell. No fractures have been observed in either porch or cell. Another cell can be seen on the remaining wall. No fractures can be seen inside this cell.

In the left verandah, trace of unit contact is seen at a height of about 3 m from the base. Near the staircase to the upper deck trace of unit contact can be seen, along which extensive weathering has taken place. Calcitic encrustation is also present.

The left verandah opens into a large cell. Half of the crown of the cell has collapsed along a unit contact. The remaining portion has started to separate from the block above and is on the verge

of collapse (Plate VII – 72). *This cell may be closed to visitors till treatment is completed.* The overhang outside the verandah has collapsed at places and small portions have been destroyed.

The Chaitya of cave 10 is supported by a colonnade of 30 pillars which separates the aisles from the nave & apse. The crown of the front aisle is arched. There are no fractures on the crown.

The crown of the nave & apse portions is domal with rock cut beams in imitation of wooden architecture. The domal crown does not show any fractures except minor ones at one or two places. Some of the decorative ribs have chipped at places.

The crown of the aisles is at a much lower level than the crown of the central portion. On the right aisle one category III fracture is present. At one or two places squeeze up structure can be observed.

On the wall of the front aisle, unit contact can be seen near the edge of the crown. Below this three or four horizontal and parallel quartz/ zeolite veins can be seen. A highly vesicular zone is also observed. These features are visible on both right and left aisles. A 5 – 10 cm thick vein with green chert filling is seen on the back wall of the cave.

The crown of the stair way to the upper deck is weathered and fractured at many places.

The crown of the left verandah on the upper deck has been cemented and no fractures can be deciphered. The verandah has one cell on the back wall. The crown of the cell is highly to moderately fractured and can be divided into two zones (Plate VII – 72). In the first zone the rock is moderately fractured with small close spaced fractures. The second zone is highly fractured and heavy water seepage is reported.



The crown of the right verandah on the upper deck has been cement plastered and no cracks could be deciphered. On the back wall of the verandah there are three cells, while on the left wall one cell can be seen. The first cell from the right on the back wall is in a highly dilapidated condition with a portion of the roof having collapsed (Plate VII – 72). The roof now resembles a dome and is criss -crossed by a number of small fractures. The walls show extensive deposition of calcium carbonate/oxalate. Water seepage is reported to be copious. The walls show moderate to high degree of weathering and bear numerous fractures, some of which have been sealed with cement.

The middle cell also has numerous fractures on the crown, which can be traced into the wall. Water seepage is reported during the monsoon (Plate VII – 71). In the cell, unit contact can be observed at a height of 60 – 65 cm from the floor. The crown appears to be flaking at places.

Inside the third cell, unit contact is seen near the base. Deposition of calcium carbonate/oxalate is seen as a large patch and seepage takes place through a crack in the wall between the two cells.

It has been noticed that the ground surface above these three cells has been cemented and a certain amount of ponding of water is taking place. All three cells thus require treatment and should be closed to visitors till the treatment is completed. In the cell opening on the left wall, unit contact can be seen at a height of at 0.30 – 0.60 cm from the base. Only a minor (category I) fracture is seen on the crown.

The treatment suggested is as follows:

1. Protection of beam/ Rafters on façade by shotcreting and microstitching.

2. Rock bolting and selective shotcreting on crown of cell on left verandah of lower deck and also part of the verandah near the staircase.
3. Selective shotcreting on crown of right verandah of lower deck and cell.
4. Microstitching of loose rock.
5. Repairing of crown of outer two cells on right side of upper deck.
6. Removal of old guniting and fresh shotcreting up to 15 m from the edge. The shotcrete zone to be merged with the existing drain.

The geological log of the crown of cave 10 is presented in plates VII – 67, 68 & 69 and section along the centerline of cave is presented in plate and plate VII - 70.

CAVE –11

Cave 11 is known as 'Do thal' although it is a three - decked cave. The lower deck was completely filled up with rubble and was later on exposed.

The entrance is through a front wall, which has almost entirely perished. The open to sky courtyard is T shaped. On the right sidewall of the courtyard is a cell. Inside the cell unit contact is seen at a height of about 1.0 -1.2 m. Pipe amygdules are present. Squeeze up structure can be seen in one corner of the cell. Pipe vesicles are mostly filled with green earth.

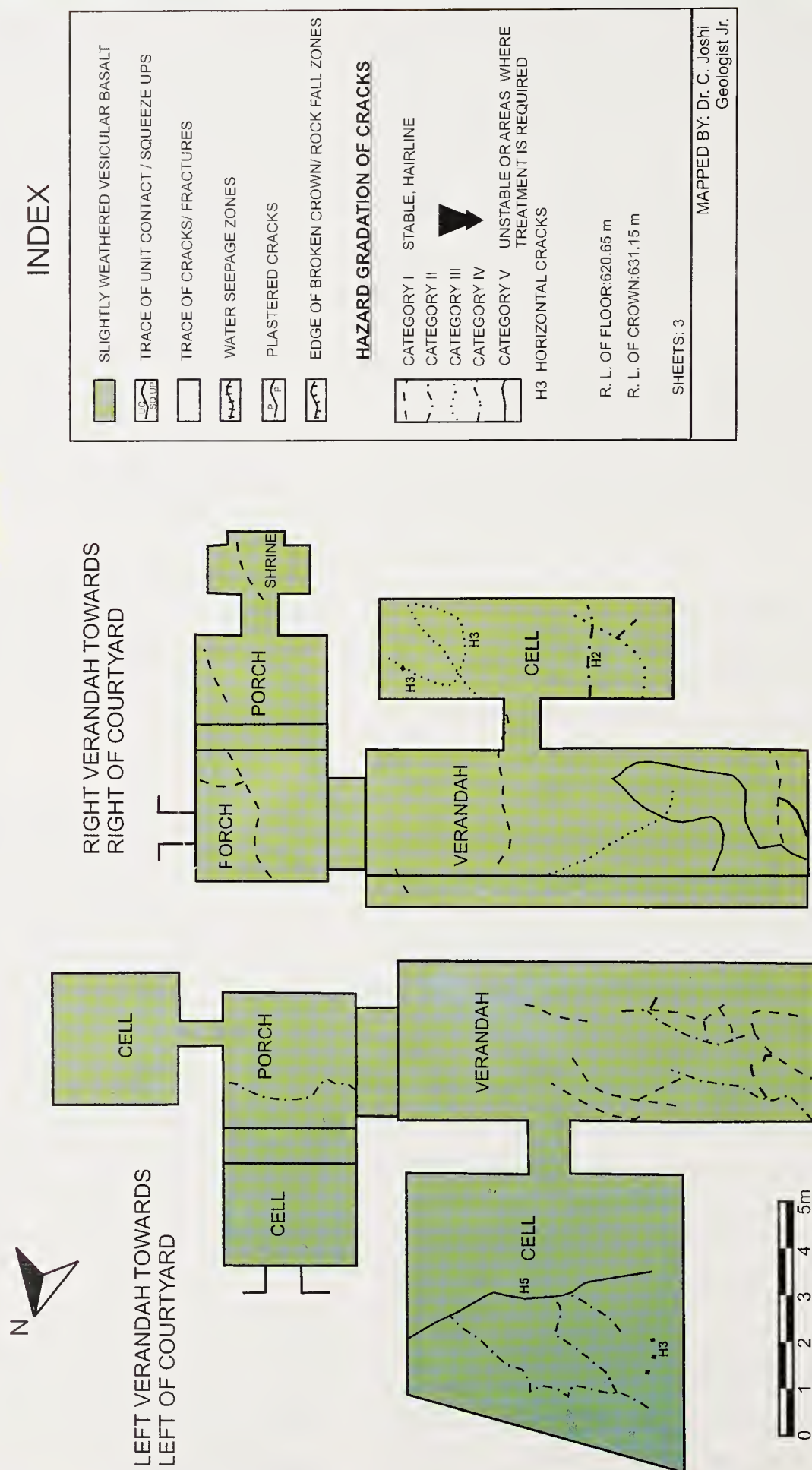
On the left wall of the courtyard is an L shaped cell. A squeeze up structure along which weathering has taken place is prominent on the crown. Numerous cracks can be seen. On the outer side, chunks of rock have fallen. Two pillars have been erected. Below the cell is a water cistern with an open manhole.



Plate : VII-67

GEOLOGICAL LOG CROWN OF OF PART OF LOWER DECK OF CAVE 10 AT ELLORA

SHEET - I



GEOLOGICAL LOG OF CROWN OF UPPER DECK OF CAVE 10 AT ELLORA

SHEET - II

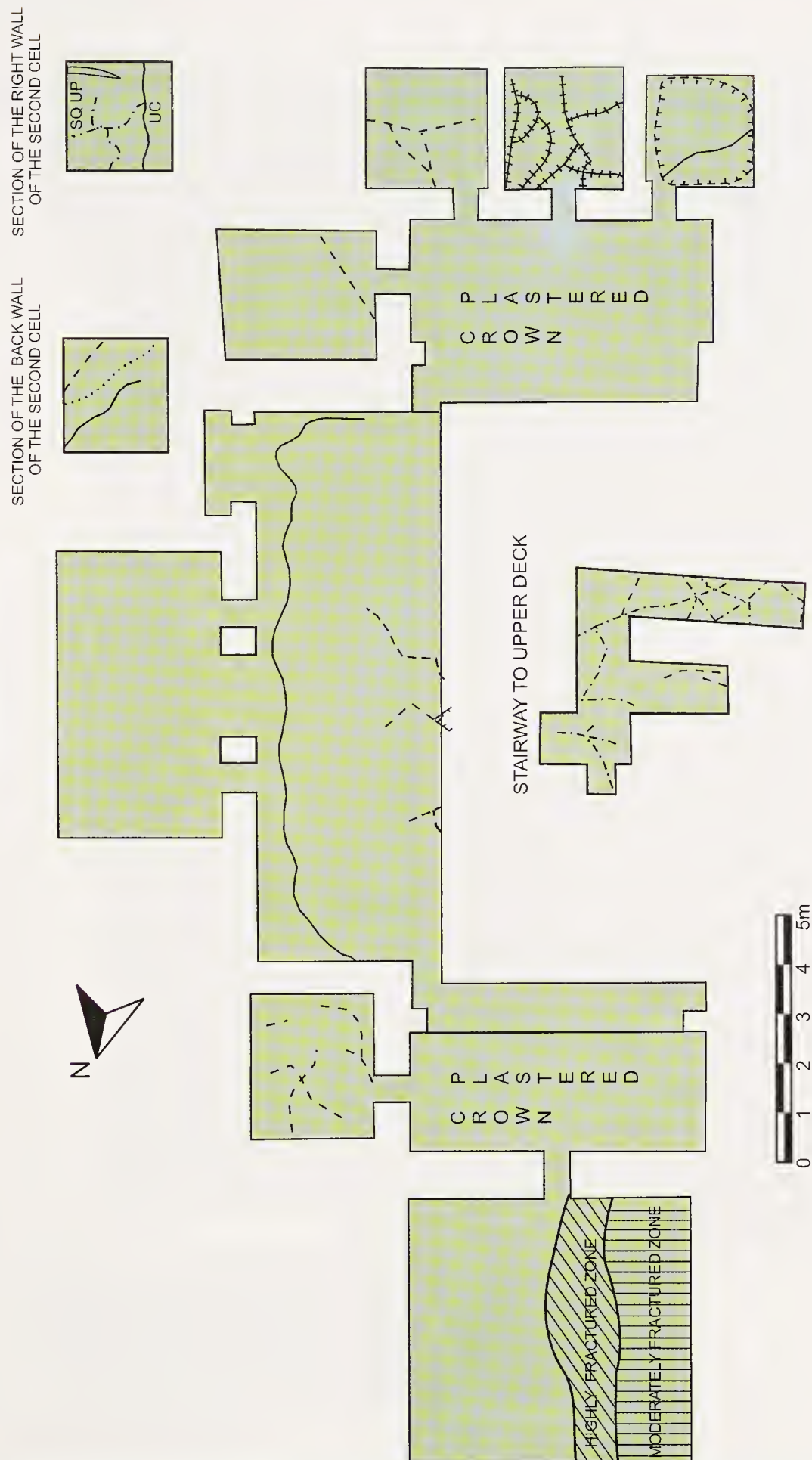
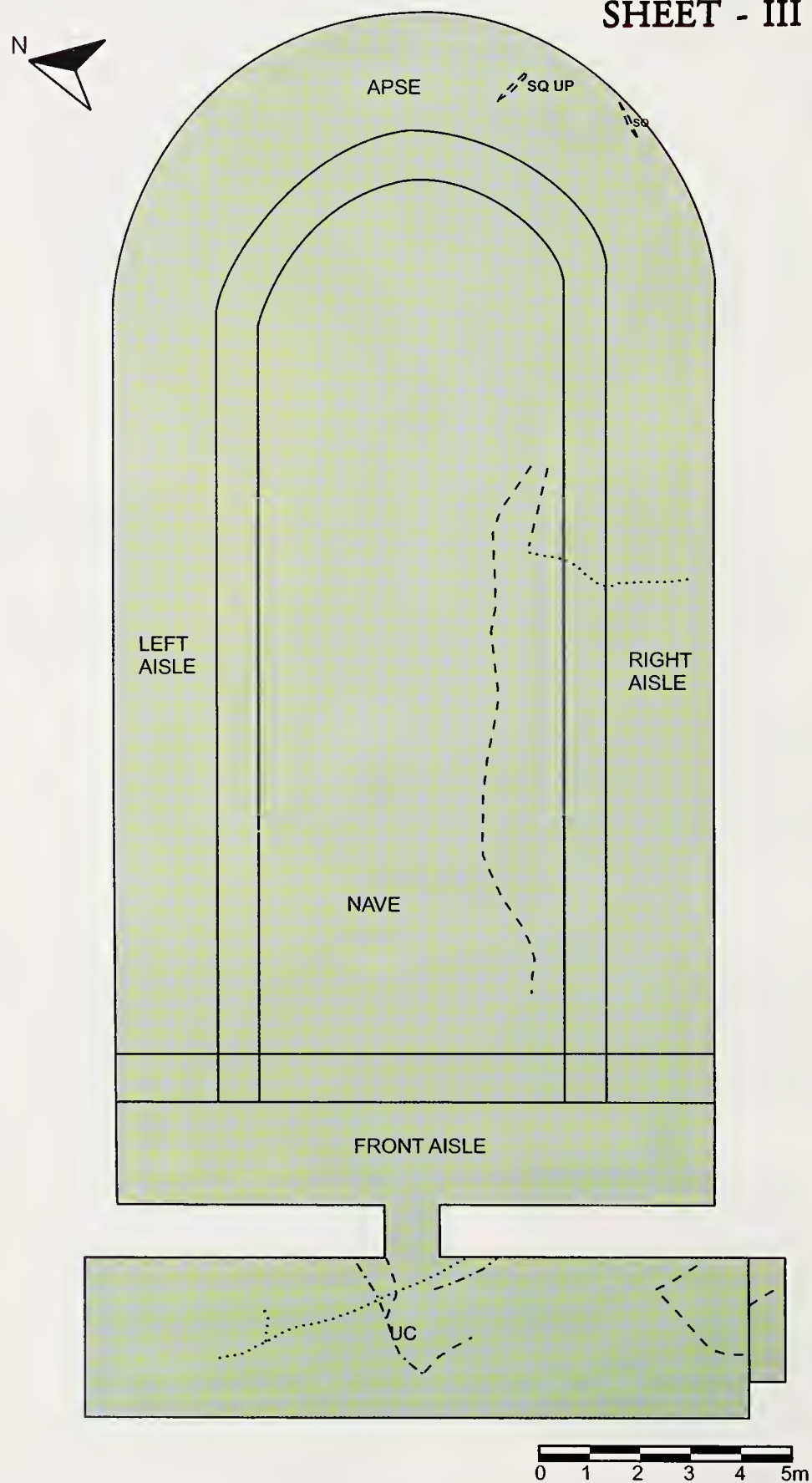


Plate : VII-69

GEOLOGICAL LOG OF CROWN OF CAVE 10 AT ELLORA

SHEET - III



GEOLOGICAL CROSS SECTION ALONG THE CENTRE LINE OF CAVE 10 AT ELLORA

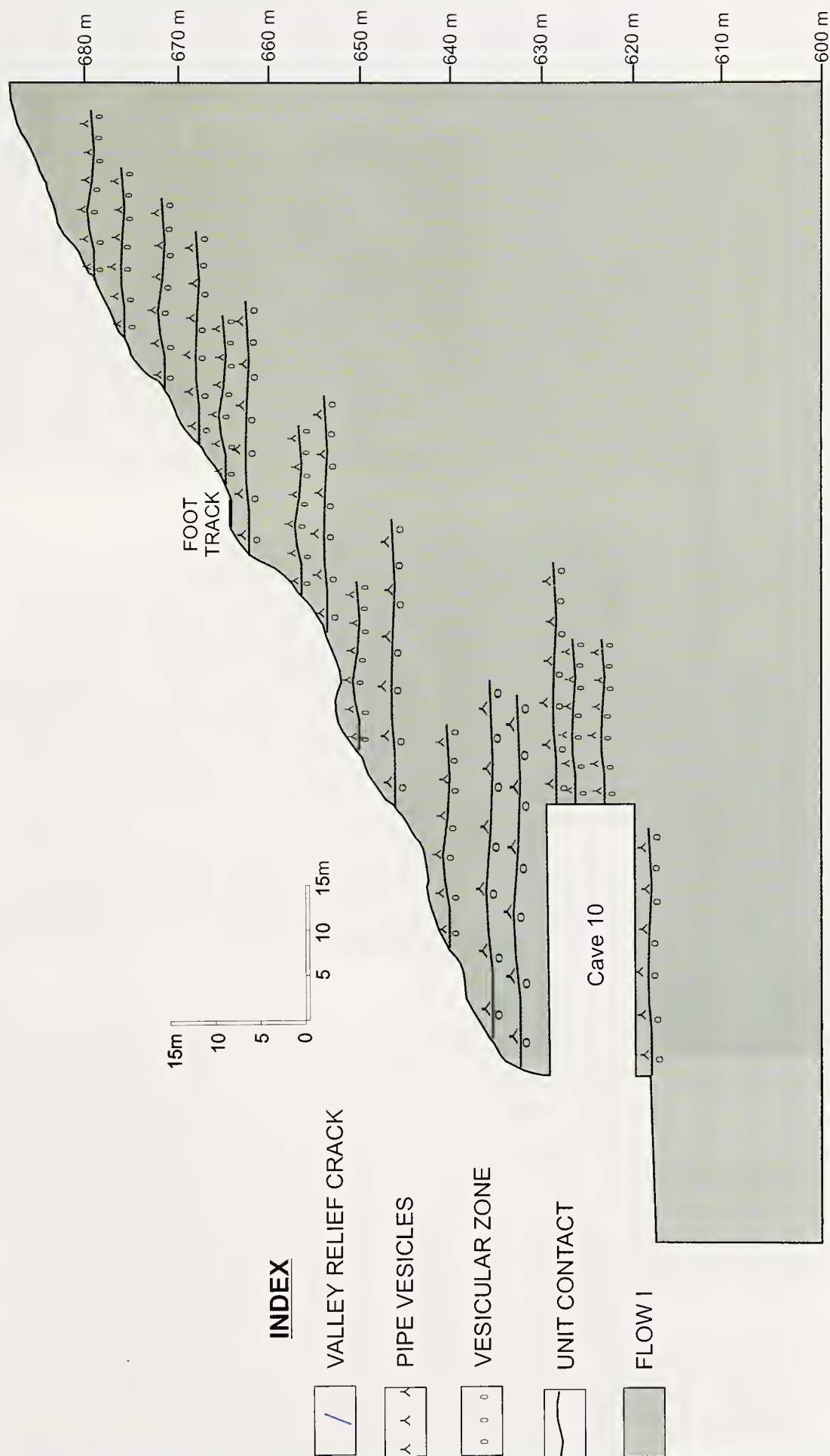
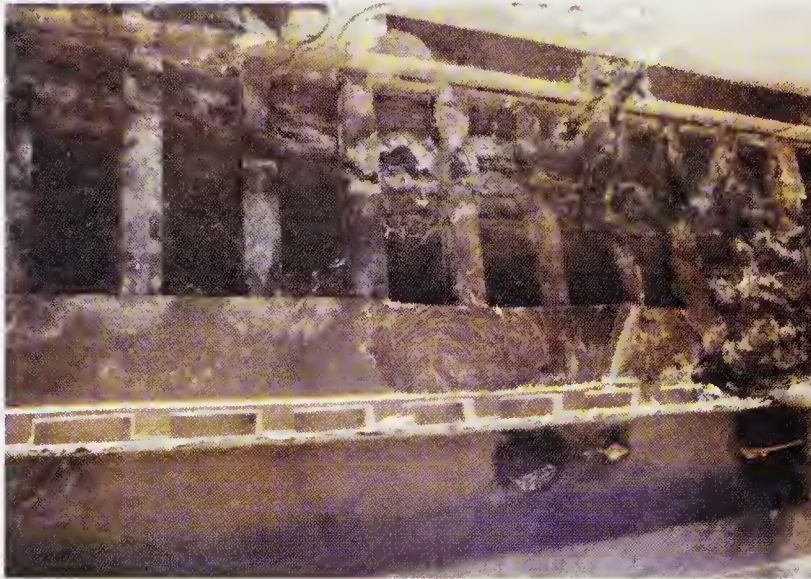


Plate : VII-71

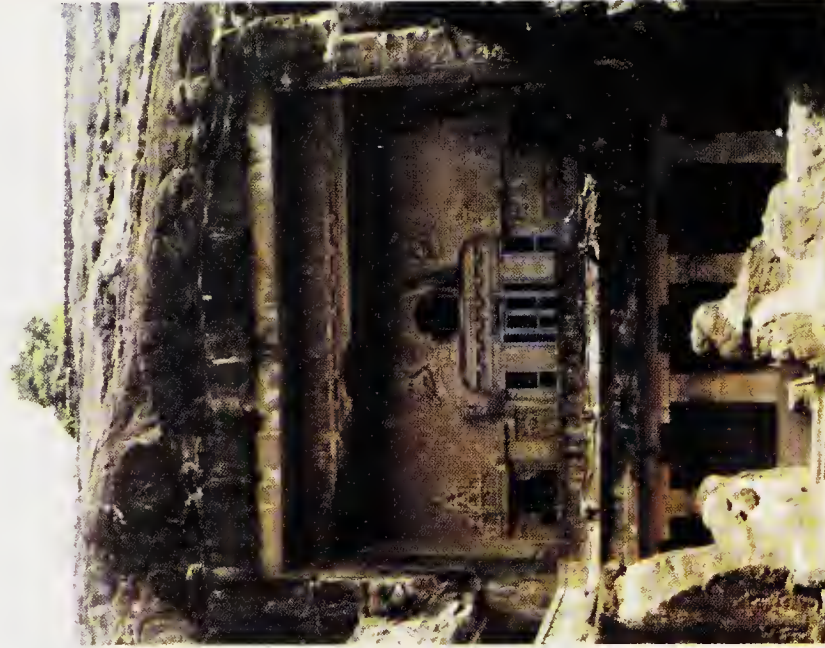
PHOTOGRAPHS OF CAVE 10 AT ELLORA



WATER SEEPAGE IN CELL ON
UPPER DECK OF CAVE 10



IMITATION RIBS ON FACADE SHOW
DAMAGE DUE TO WEATHERING

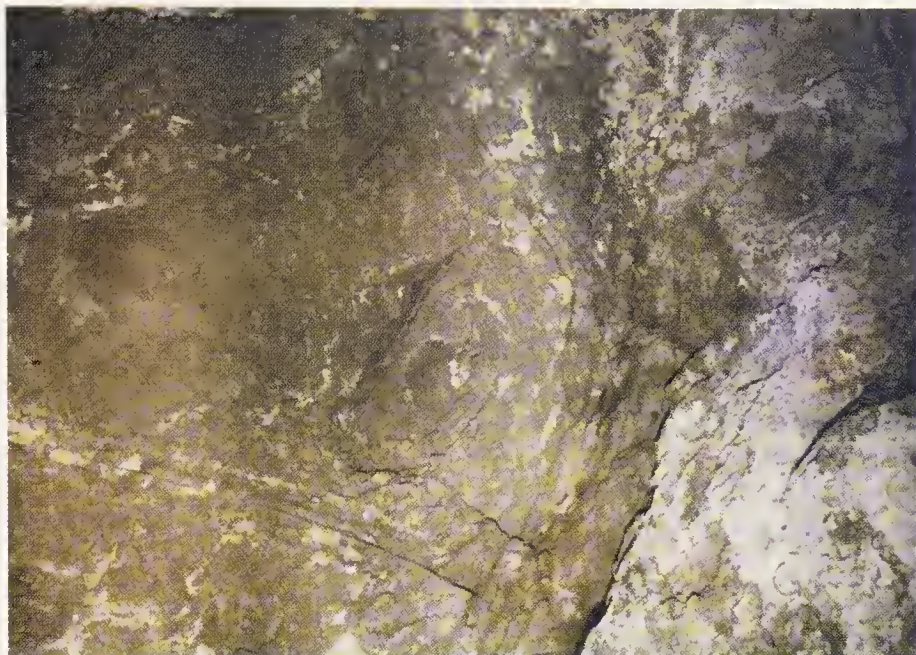


FACADE OF CAVE 10 WEATHERING IS PROMINENT

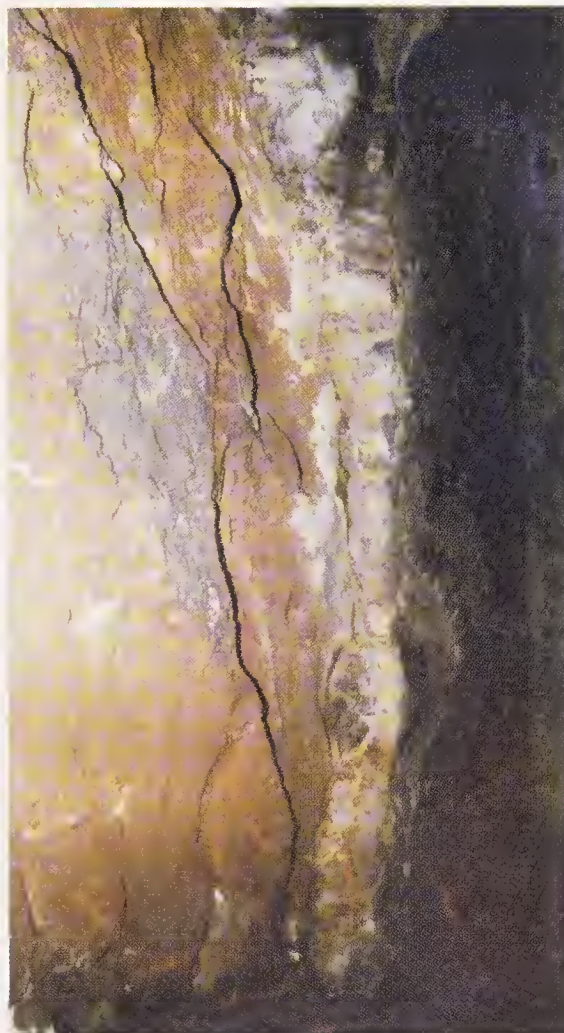
PHOTOGRAPHS OF CAVE 10 AT ELLORA



HIGHLY FRACTURED ZONE ON CROWN OF CELL
ON UPPER DECK OF CAVE 10



EXFOLIATION TYPE OF WEATHERING
ON CROWN OF CELL ON UPPER DECK
CAVE 10



BLOCK IN PROCESS OF DETACHING ON CROWN OF
CELL ON LOWER DECK OF CAVE 10



The lower deck of cave 11 consists of a long verandah having 8 large square pillars. The verandah opens into a shrine in the central part. On either side of the shrine is a cell. Unit contact can be seen at a height of 1.0 to 1.2 m from the floor. The crown of the verandah contains numerous category I cracks. Another unit contact can be seen near the crown. On the left side is a staircase leading to the middle deck.

The middle deck of cave 11 consists of a long verandah approached through a flight of steps on the left side. At the extreme left end of the verandah is a small cell that leads to the upper deck. Just above the steps is a small & unfinished cell. On the walls of the cells and the verandah, unit contact can be seen at a height of 1.5 to 2.0 m. On the extreme right of the verandah is a small shrine. Minor fractures are present on the crown. A cell is seen on the right side of the verandah near the shrine. Minor fractures are present on the crown of this cell.

In the center of the verandah is the entrance to the antechamber and a shrine. The antechamber is divided into two sections by a beam supported by two large square pillars. Minor cracks can be seen on the crown of the verandah. Below this unit contact, three horizontal and parallel quartz veins can be seen on the wall of the verandah.

On either side of the antechamber, the verandah opens into two shrines (one on either side). No fractures have been observed on the shrines.

The upper deck consists of a long verandah approached by flight of steps from the left. The crown of the verandah is supported by eight pillars. The overhang has been partially destroyed at one or two places.

In the verandah, unit contact can be seen just at the floor level and its trace can also be seen on

the floor. On either side of the verandah is a cell. The cell on the left has been left uneven and does not contain any fractures.

In the central part, the verandah opens into another verandah, which is also rectangular in shape. Inside this is a long rectangular hall, which is divided into two sections by a colonnade of eight pillars. Further inside is the antechamber & shrine. At the ends are two aisles, which open into the outer verandah. Remnants of original plaster can be seen at most places in the hall, antechamber and shrine.

Unit contact can be seen at a height of about 60 cm from the floor, in the antechamber. Trace of the unit contact can also be seen on some of the pillars. Vugs can be seen at one or two places. Minor category I fractures are noted in the verandah.

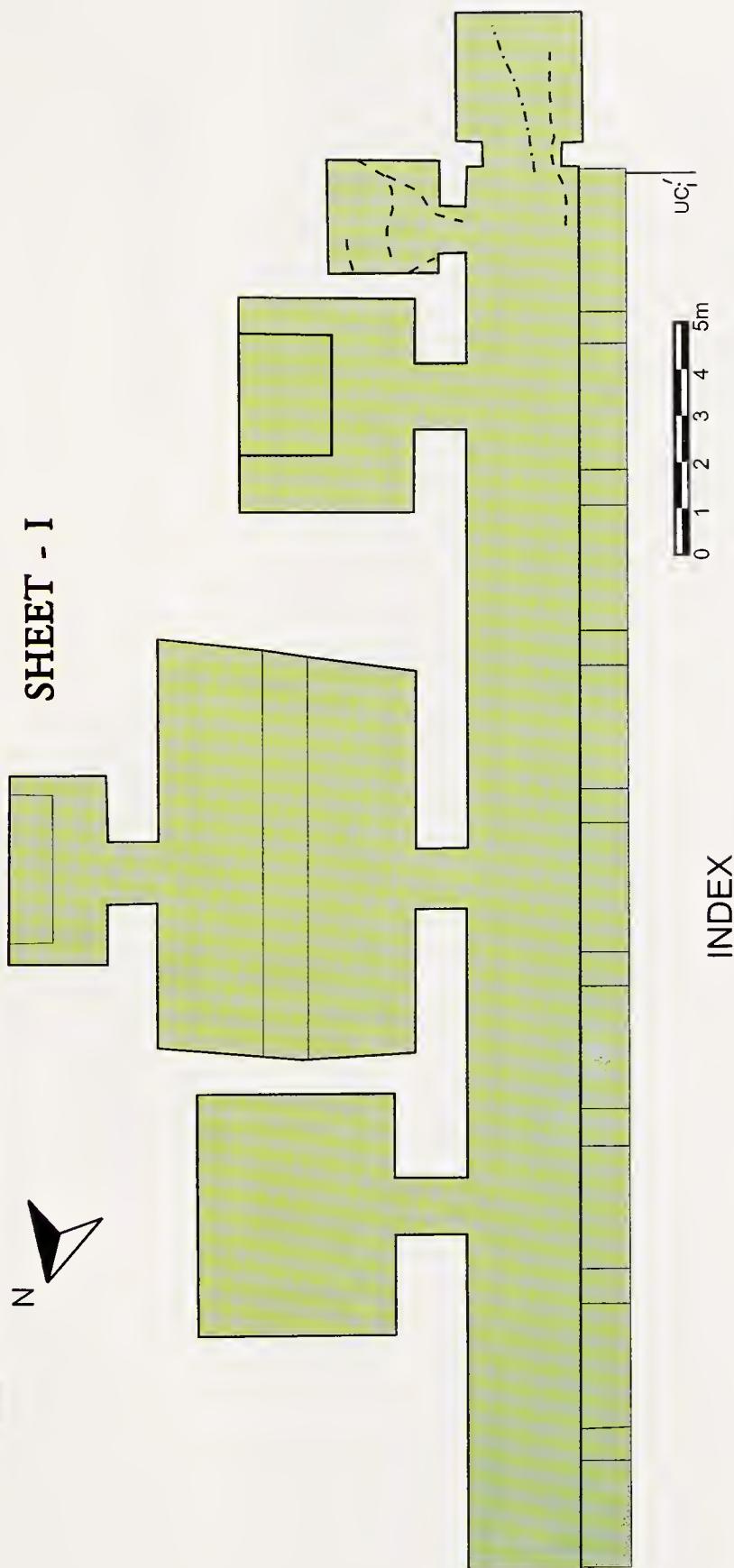
On the right side of the verandah trace of another unit contact can be observed at about 2 m from the base. The cell on the right side does not show any fractures. Pipe amygdules are seen above the unit contact.

The suggested treatment is as follows:

- 1) Shotcreting of the façade and extending it up to 20 m on the top keeping the existing drain.
- 2) A top drain above the shotcrete to be provided.
- 3) Shotcreting of the crown of the cell on the left of the courtyard.
- 4) Training of the nala between caves 11 & 12.

The geological log of the crown of cave 11 is presented in plates VII -73, 74, 75 & 76 and section along the centerline of cave is presented in plates and plate VII - 77.

GEOLOGICAL LOG OF CROWN OF MIDDLE DECK OF CAVE 11 AT ELLORA



	SLIGHTLY WEATHERED VESICULAR BASALT
	TRACE OF UNIT CONTACT / SQUEEZE UPS
	TRACE OF CRACKS/ FRACTURES
	EDGE OF BROKEN CROWN/ ROCK FALL ZONES

	CATEGORY I	STABLE, HAIRLINE
	CATEGORY II	
	CATEGORY III	
	CATEGORY IV	
	CATEGORY V	UNSTABLE AREAS WHERE TREATMENT IS REQUIRED

TOP DECK	R. L. OF FLOOR: 632.07 m
	R. L. OF CROWN: 634.92 m
MIDDLE DECK	R. L. OF FLOOR: 627.72 m
	R. L. OF CROWN: 630.77 m
LOWER DECK	R. L. OF FLOOR: 622.87 m
	R. L. OF CROWN: 625.42 m
SHEETS: 4	

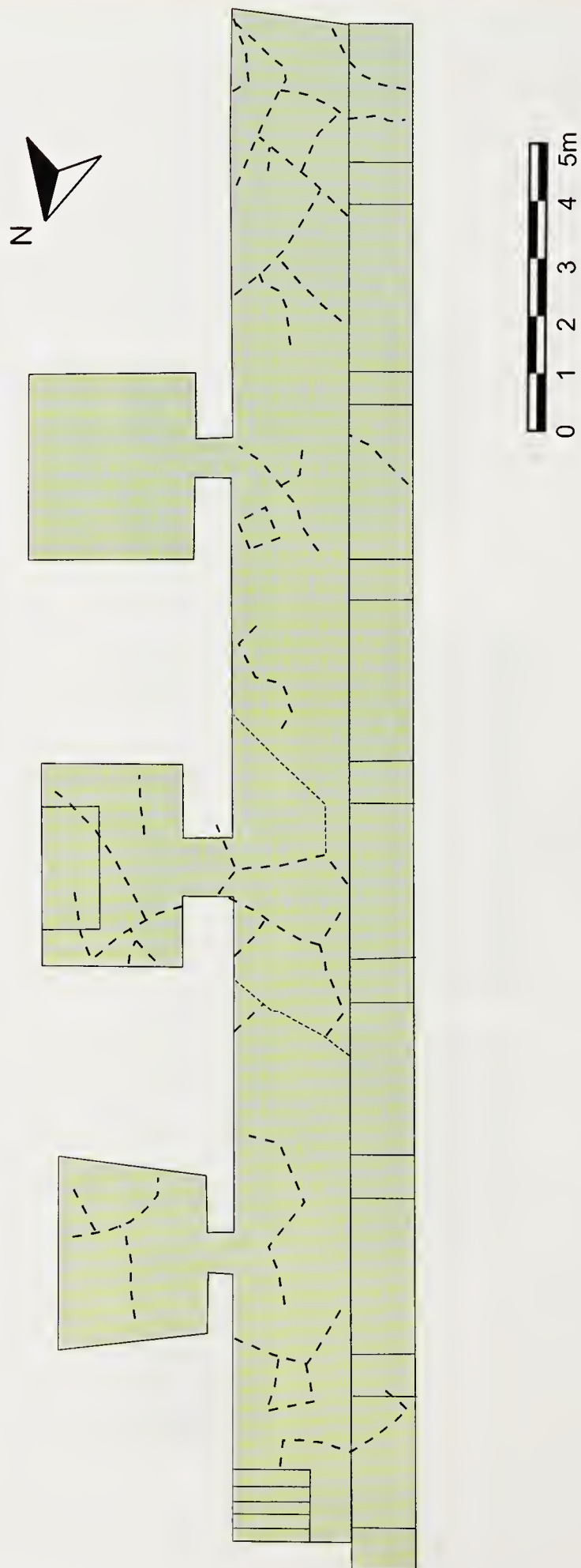
MAPPED BY: Dr. C. Joshi Geologist Jr.	
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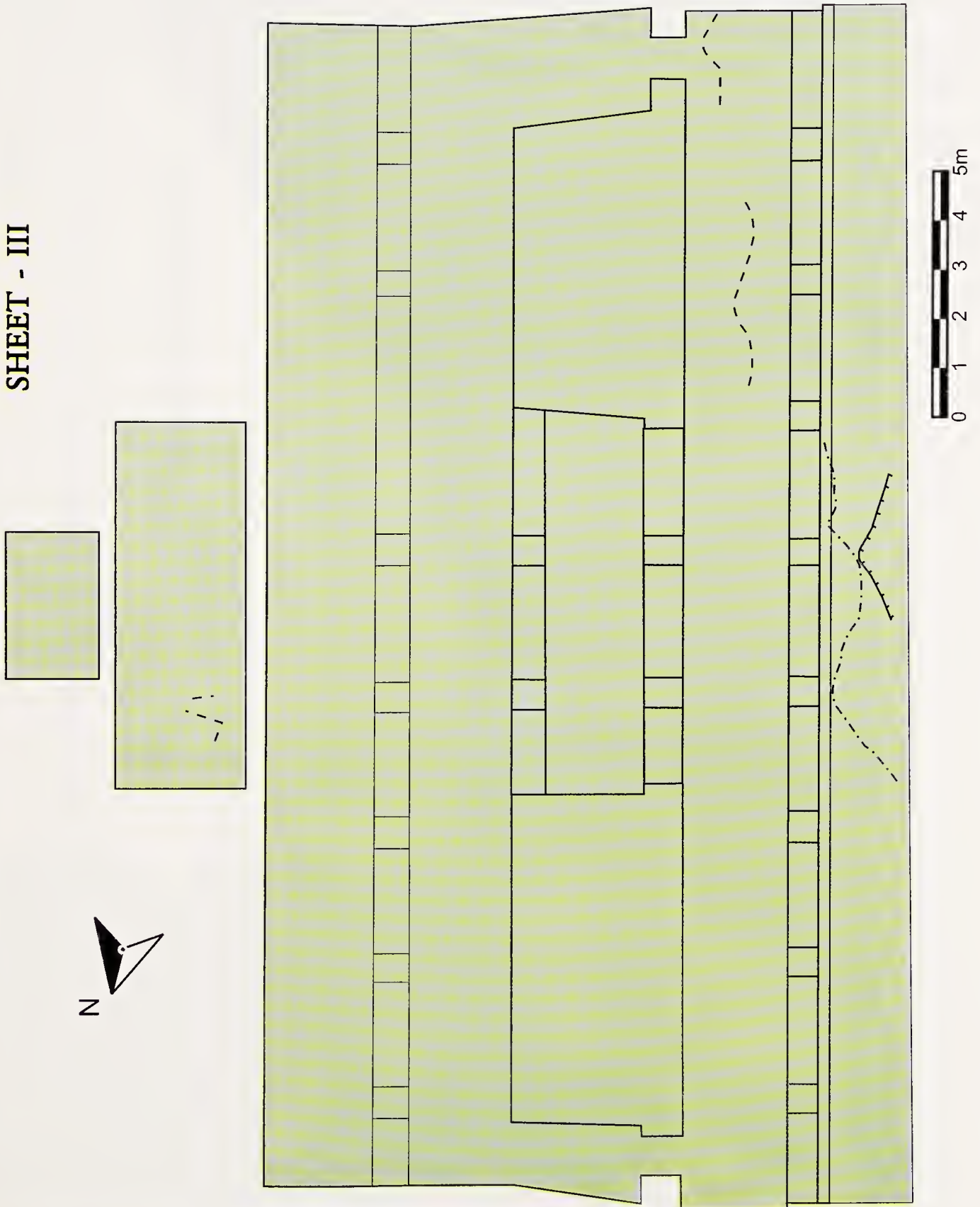


Plate : VII - 74

GEOLOGICAL LOG OF CROWN OF LOWER DECK OF CAVE 11 AT ELLORA

SHEET - II



GEOLOGICAL LOG OF CROWN OF UPPER DECK OF CAVE 11 AT ELLORA**SHEET - III**

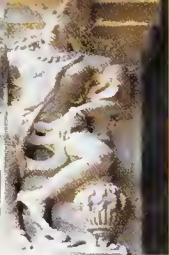
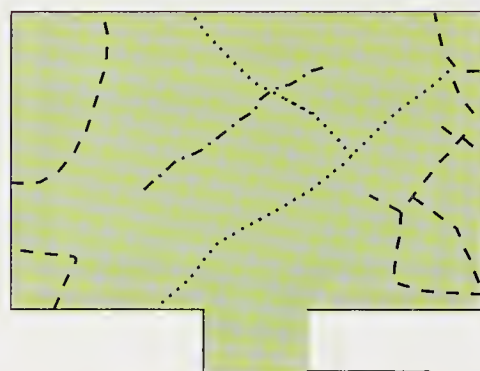


Plate : VII-76

GEOLOGICAL LOG OF CROWN OF PART OF CAVE 11 AT ELLORA

SHEET - IV
CELL ON RIGHT WALL OF
THE COURT YARD



CELL ON THE LEFT WALL OF THE COURT YARD

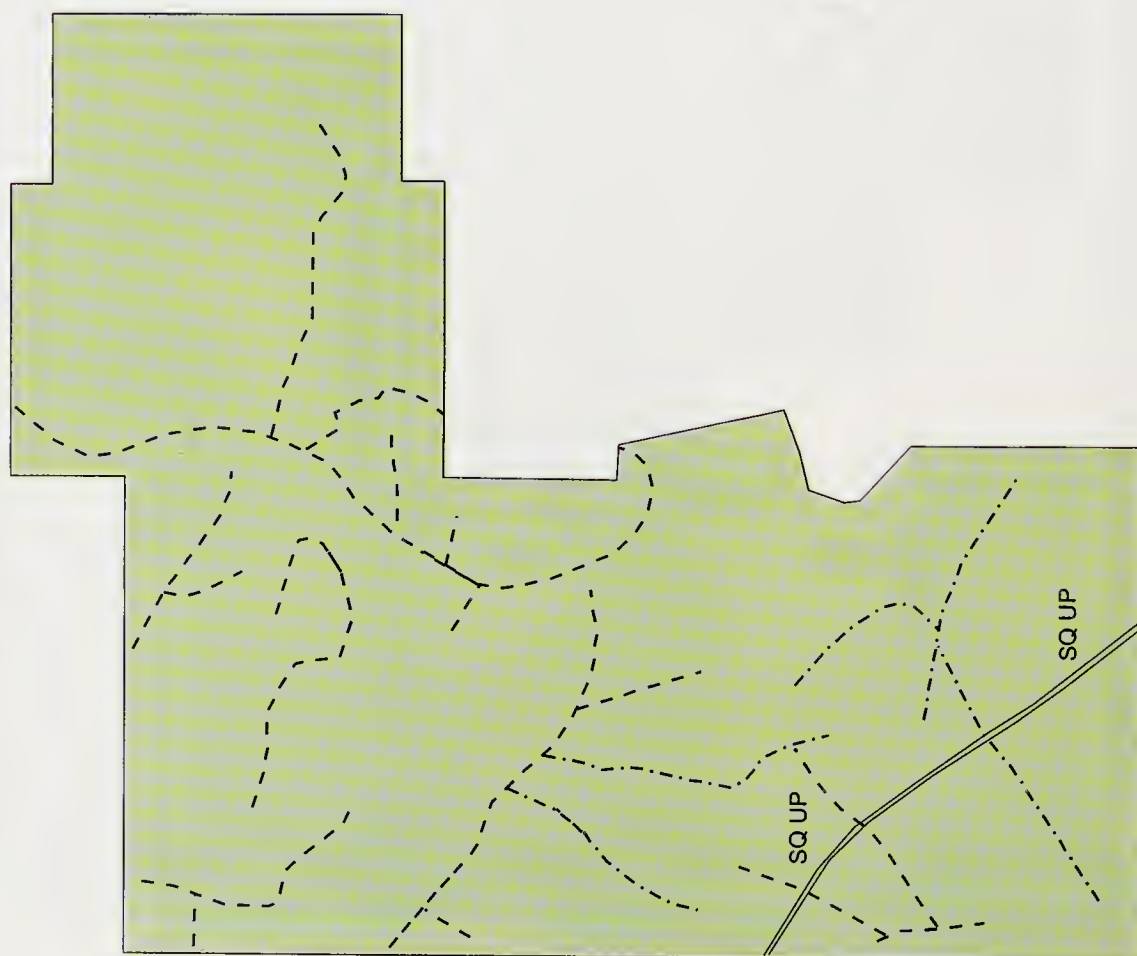
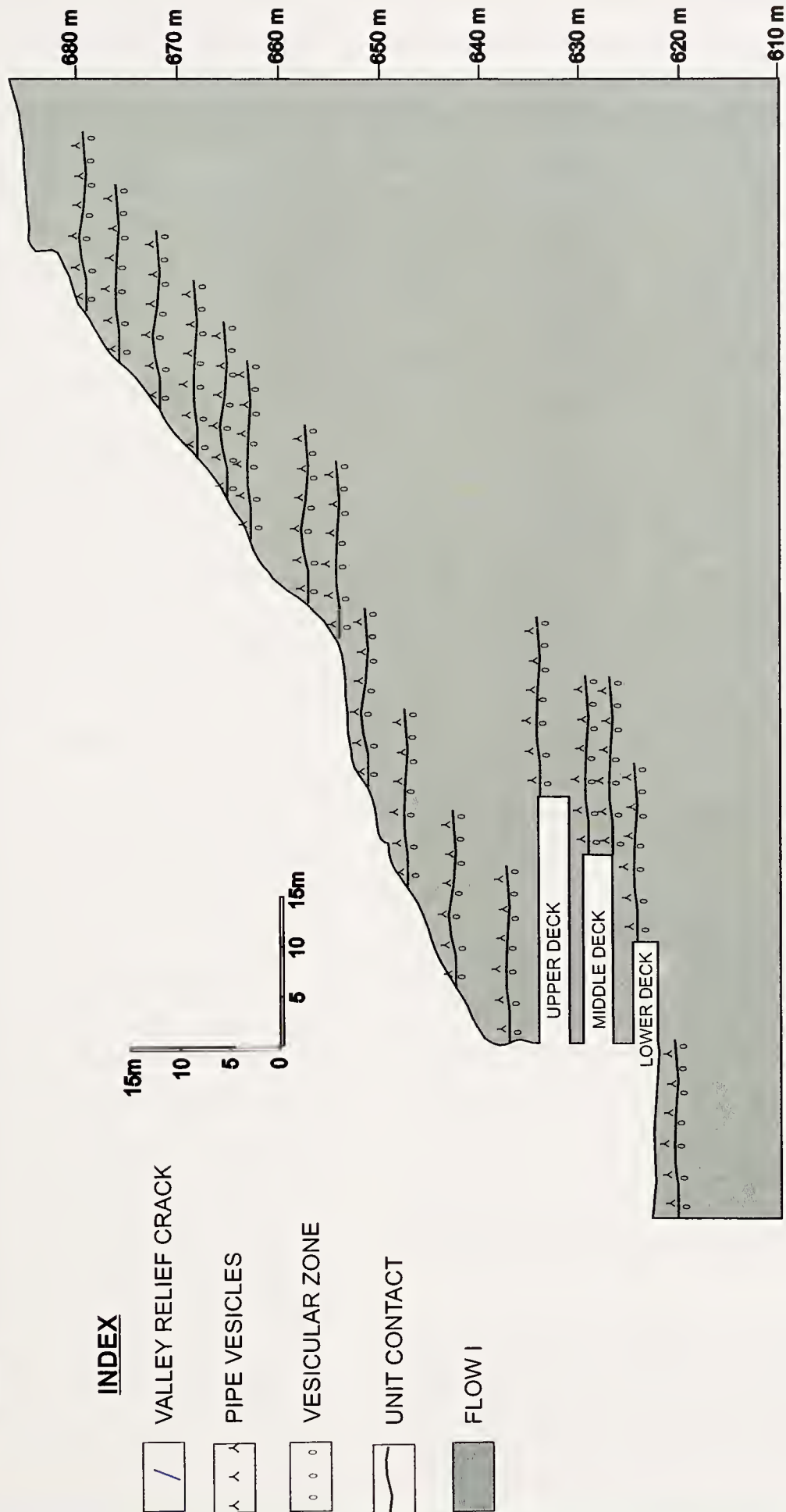




Plate : VII-77

GEOLOGICAL CROSS SECTION ALONG THE CENTRE LINE OF CAVE 11 AT ELLORA





CAVE - 12

Cave 12 is a three decked cave and can be approached through an entrance or gate. The sidewalls of this gate though a little weathered are still intact. The roof of this entrance has perished.

Inside is a large T shaped courtyard. On the left (northern) side of the courtyard is a cell approached by a flight of steps at a height of 2.20m from the floor of the courtyard. In the center of the floor of the cell is a rectangular opening to a water tank.

Inside the cell, unit contact can be seen at a height of 0.30 to 1.0 m from the floor. Pipe amygdules can be seen above the contact. Category I & II fractures are noted on the crown of the cell. An ingenious system of harvesting rainwater can be observed here. Surface run off from the slope above the cave is made to flow vertically down the wall of the courtyard and from where it is channeled into the water tank or cistern. The pillars of the cell show grade II to grade III of weathering.

On the right (southern) wall of the courtyard immediately after the entrance is a cell situated at a height of 5m from the floor. A part of the crown of the cell is in a precarious condition. Shotcreting with rock bolting is suggested to increase strength of the rock and arrest rock fall. The last few steps leading to this cell are extremely narrow and it is difficult to climb them. *It is recommended that this cell may be closed to visitors because of this hazard.*

Further inside, on the right wall of the courtyard at ground level is a small verandah with unfinished cells. Category II fractures can be seen on the crown. Some water seepage has probably been taking place in the verandah.

Cave 12 is a three-decked cave. The façade of the top deck is marred by rock fall. At many places formation of micro-stalactites has been observed. On the right side (south), the collapse of the façade/overhang is along a highly fractured zone. This zone dipping about 55° W at the lower level appears to be shallower at top. Water seepage in the form of a continuous drip is seen from a number of locations. The seepage is through the highly fractured zone. Behind the cut face, on the roof of the cave there is a retaining wall and a drain placed behind it. The recharge zone is the area behind the retaining wall up to the first micro scarp, west of the foot track leading to Khultabad. On the up-slope side of this foot track is a drain, which is made to flow towards north along the hill slope. Proper lining of this drain will stop/ reduce percolation of water.

Surface treatment of the area between the micro-scarp and the drain/retaining wall behind the cut face will act as the second line of defence. Surface treatment will include construction of a drain at the foot of the micro-scarp to divert any water flowing down through the weathered soil zone and recharging the fractured zone through which water seeps. Stripping of soil in this zone followed by laying of an impervious layer (geosynthetic or shotcrete) and later followed by relaying of the stripped soil with grass cover will adequately take care of the water seepage. Part of the façade overhang where the fractured zone is exposed can be shotcreted (with provision of drainage holes) to increase strength of the rock and to arrest further weathering & rock fall.

At the landing level between the middle and upper decks on the left (northern) side of the cave water seepage is seen from the crown of the staircase. The seepage is in the form of a few droplets and a



moist zone. Just above the crown of the staircase on the hill slope is a highly fractured and weathered zone, covered by soil. This zone is intersected by a very gently eastward sloping unit contact. The water that accumulates in the soil – weathered - fractured zone is transported along the unit contact and drips through the vertical crack in the crown of the staircase. This seepage zone is restricted to the outer 2-3 m of the hill slope.

Water seepage is also seen in the cell on the right side (southern) of the cave at the landing level between the lower and middle decks through a vertical crack. Just above the crown of the cell, a highly fractured and weathered zone, covered by soil is observed. This zone is intersected by a very gently eastward sloping unit contact. The water that accumulates in the soil – weathered - fractured zone is transported along the unit contact and drips through the vertical crack in the cell.

The entrance to the top deck is through a flight of steps and into a cell on the left (northern) side of a large rectangular hall. The hall is divided into five sections by four colonnades, each of eight pillars. An antechamber leads into the shrine.

Unit contact is seen at the level of the crown and its trace can be seen on the crown at many places. The fifth, sixth & seventh pillars of the outermost row show weathering along the unit contact, which is situated at the junction of the capital (beam), and the pillar. Some shotcreting or other treatment may be essential to increase strength & arrest further weathering. Some weathering is also seen along squeeze up structure in the front aisle.

At a few places small parts of the crown have collapsed and these have been delineated. No treatment may be required at these places.

Remnants of plaster and paintings can be seen

on the crown. On the walls 4-5 parallel quartz/zeolite veins can be seen. There are no fractures on the crown of the antechamber and shrine.

The middle deck of cave 12 consists of a verandah that opens in the central part, into a small aisle, which in turn leads to a large hall. On the sides of the hall are numerous cells. There are no fractures in any of the cells, which are mostly covered by original plaster. Unit contact can be seen at two levels, the lower one at a height of about 1.0-1.2 m from the floor while the second one is at about 2.7 to 3 m. Pipe amygdulites can be seen over unit contacts. Only minor category I & II cracks can be seen on the crown of the middle deck.

The bottom deck of cave 12 consists of a large hall divided into a number of aisles by rows of pillars. A large antechamber leads to a shrine. On the sidewall of the antechamber as well as the halls are a number of cells.

On the bottom deck, unit contact is seen at a height of about 1 m from the floor. Pipe amygdulites are present.

Treatment measures suggested are as follows:

- 1) Rock bolting and reinforced shotcreting of the façade in the top most part.
- 2) Discharging of the upper drain into the nala.
- 3) Plain shotcrete on the rock ledge on either side.
- 4) Boulder packing and shotcreting in cavities along the fracture zone (dipping 45°W) on the rock ledge.
- 5) Providing windows for draining water.

The geological log of the crown of cave 12 is presented in plates VII – 78,79, 80, & 81 and section along the centerline of cave is presented in plate VII - 82.



Plate : VII-78

**GEOLOGICAL LOG OF CROWN OF LOWER DECK
OF CAVE 12 AT ELLORA**

SHEET - I

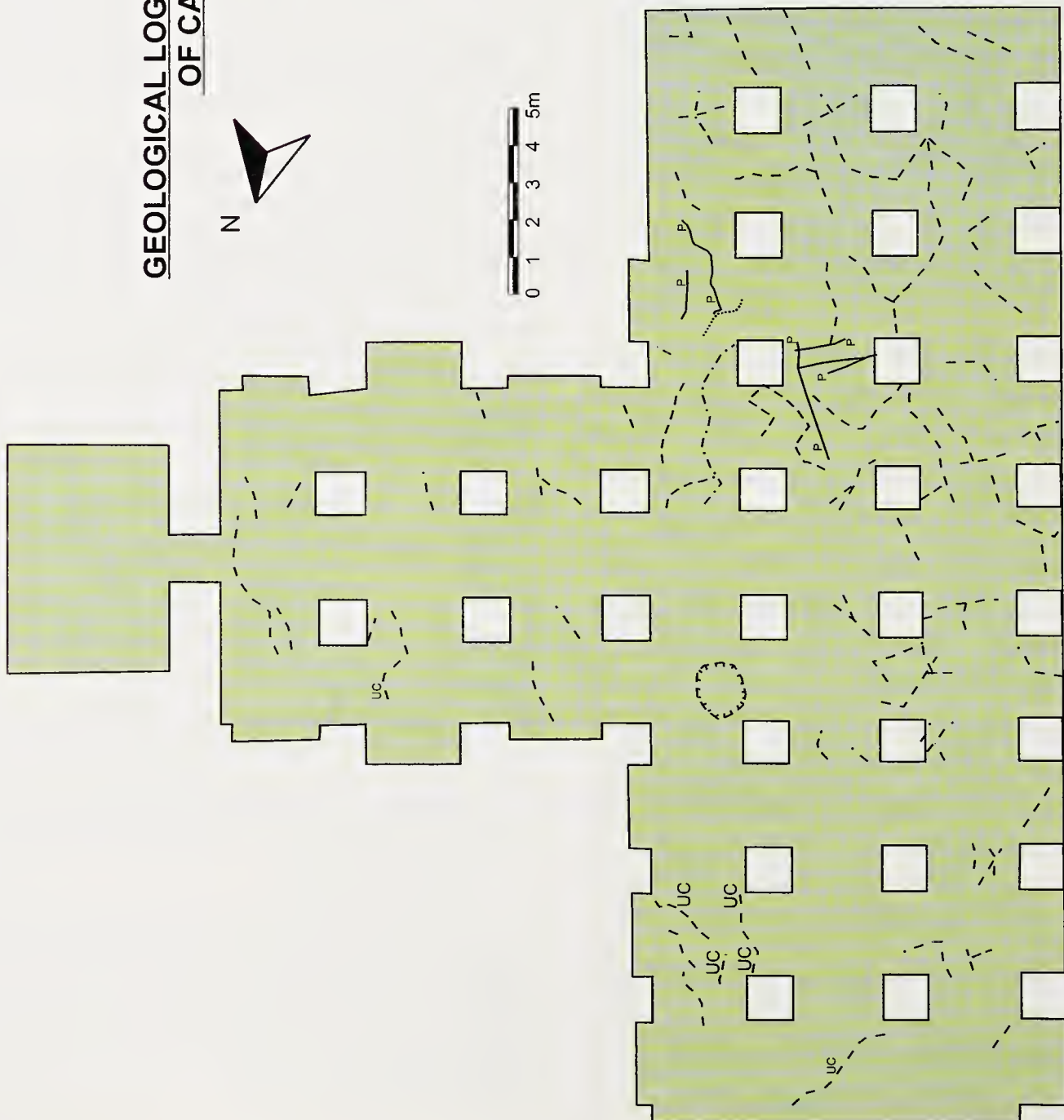


Plate : VII-79

**GEOLOGICAL LOG OF CROWN OF MIDDLE
DECK OF CAVE 11 AT ELLORA**

SHEET - II

0 1 2 3 4 5m

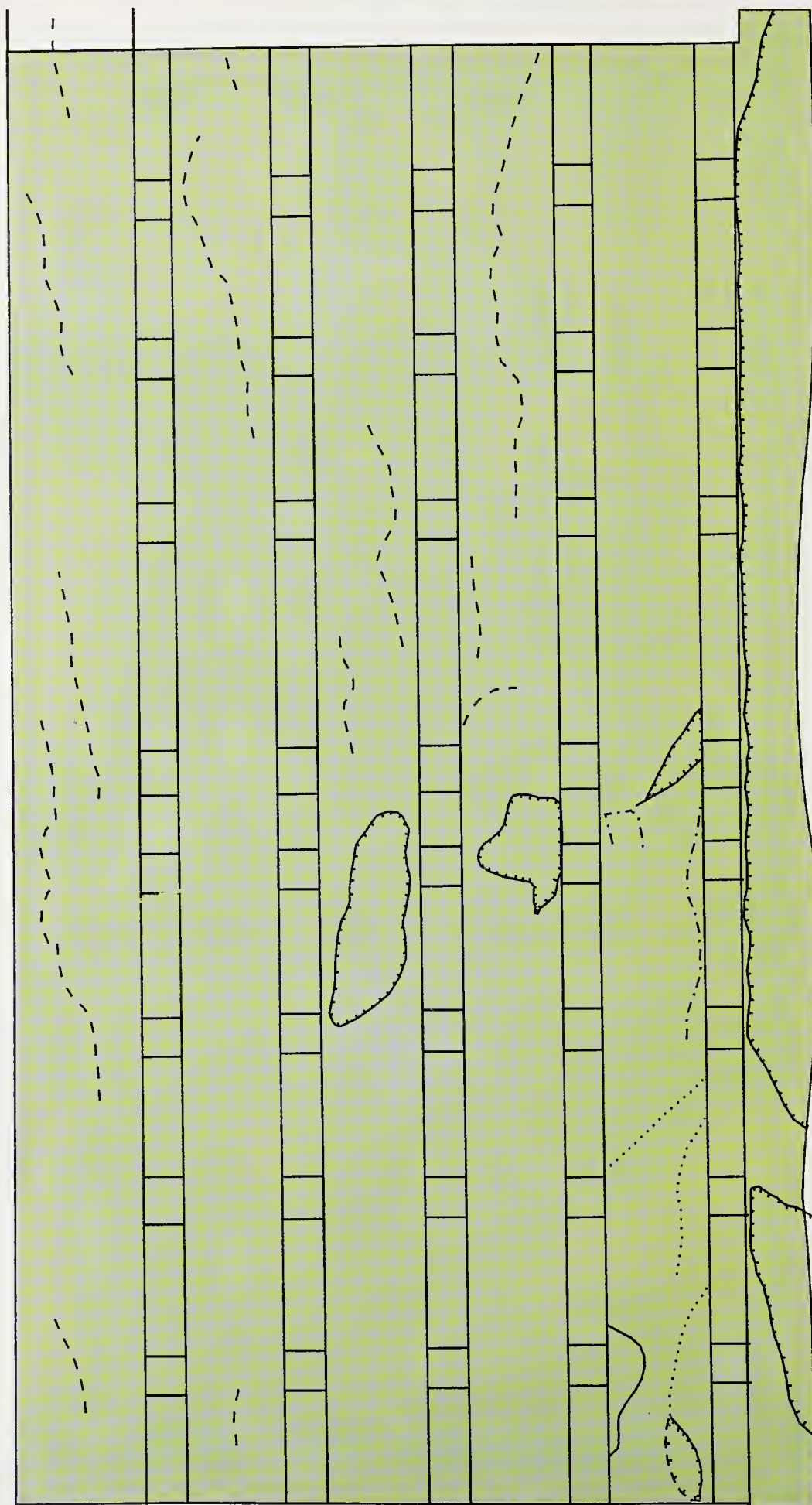
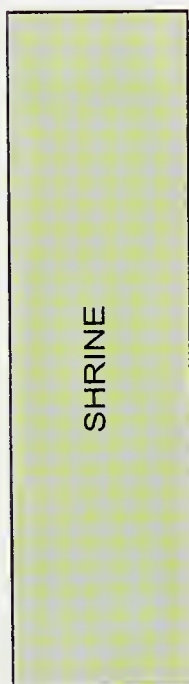




Plate : VII-80

GEOLOGICAL LOG OF CROWN OF TOP DECK OF CAVE 12 AT ELLORA

SHEET - III

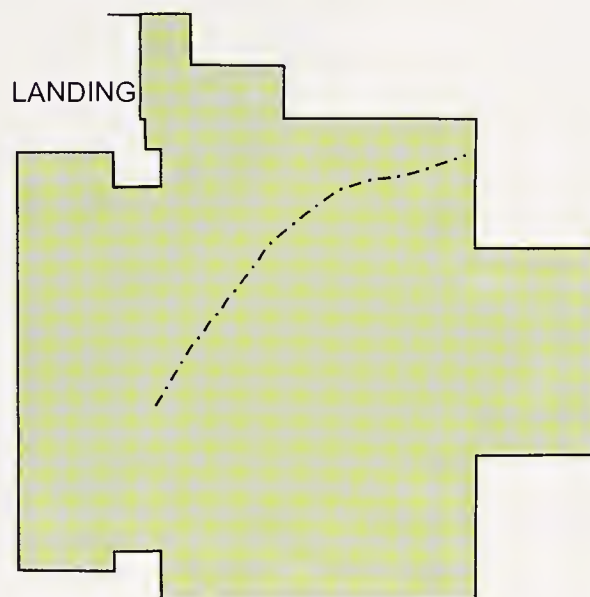


GEOLOGICAL LOG OF CROWN OF PART OF CAVE 12 AT ELLORA

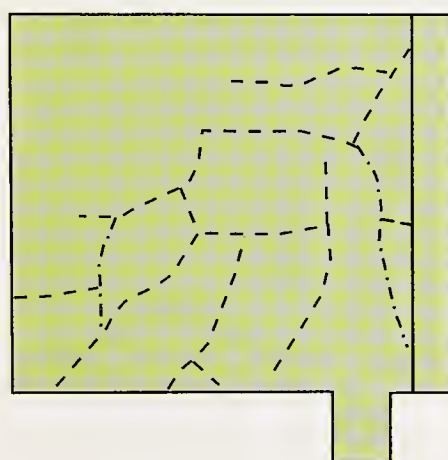
SHEET - IV

CELL AT LANDING LEVEL BETWEEN
LOWER & MIDDLE DECKS
(ON RIGHT WALL OF COURTYARD)

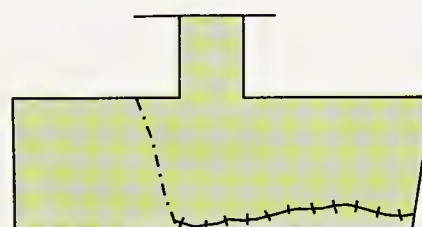
CELL TO THE RIGHT OF VERANDAH
OF MIDDLE DECK



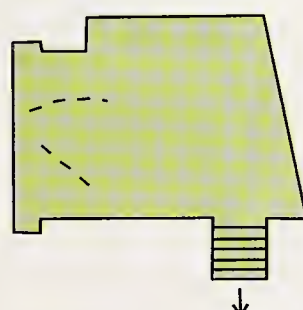
CELL ON LEFT WALL OF COURTYARD



VERANDAH & PARTIALLY EXCAVATED CELL ON
RIGHT WALL OF COURTYARD AT GROUND LEVEL



CELL TO THE RIGHT OF VERANDAH
ON LOWER DECK



TO MIDDLE DECK

CELL ON TOP OF ROCK CUT GATEWAY
ON RIGHT SIDE

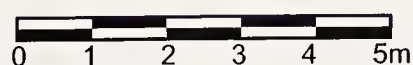
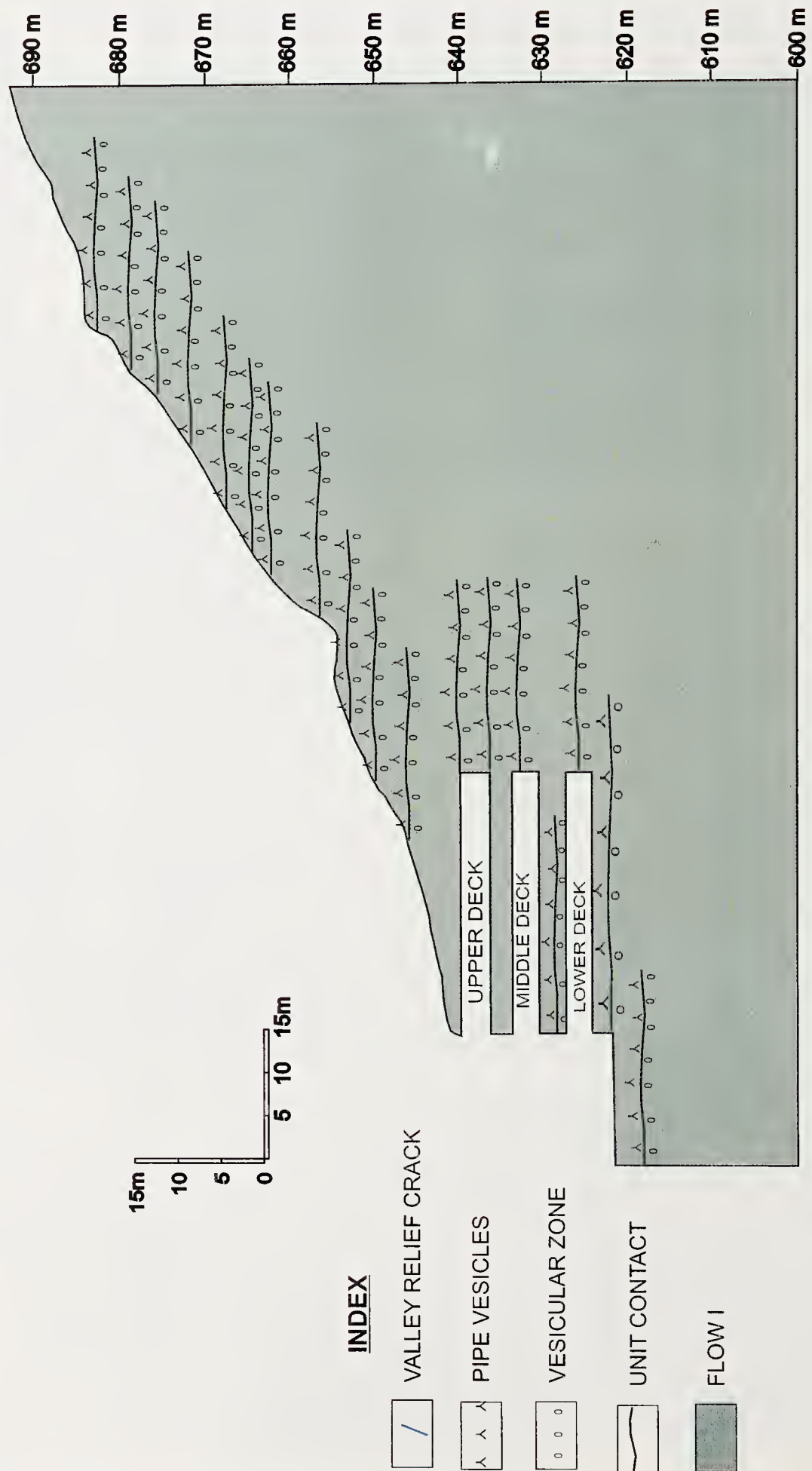


Plate : VII-82

GEOLOGICAL CROSS SECTION ALONG THE CENTRE LINE OF CAVE 12 AT ELLORA





CAVE - 13

Cave 13 is a small rectangular cave without any ornamentation. Outside the present surviving portion of cave 13, evidences of some other structures can be seen on the floor. This zone extends for about 10 m outside the present cave. Unit contact can be seen at a height of about 1 m from the floor. The right side of the entrance is somewhat intact while the left side is broken. A few cracks falling in category III are seen on the crown of the cave. Towards the right side, the crown shows patches of zeolite material.

The floor of the cave is covered by residual soil (?) attesting to grade VI of weathering. The back wall and crown show grade-II weathering as also the outer wall.

No sculptures are present in the cave. Seepage noted is in the form of moist patches on the inside of the front wall on the left side. The unit contact serves as the conduit for surface run-off to seep inside.

Treatment measures suggested are as follows:

- 1) Reinforced shotcrete with provision of drainage holes in the negative slope above caves 13 & 14.
- 2) Plain shotcrete below cave 13 and above caves 13& 14.
- 3) Shotcrete to be extended for 20 m on top. Top drain to be constructed and end of shotcrete discharge to be led to nala above 14.
- 4) Training & lining of nala

The geological log of the crown of cave 13 is presented in plate VII – 83 and section along the centerline of cave is presented in plate VII - 84.

CAVE 14

Cave 14 is a small cave consisting of a hall with four aisles surrounding it, a shrine with a walkway around it. The central hall is supported by 12 pillars, while the cave portal is supported by 4 pillars. Unit contact is seen at a height of 3.5 – 4.0 m from the floor, on the crown. Trace of squeeze up structure is also seen. The crown of the right aisle shows trace of unit contact and minor cracks. On the back aisle, Grade III fractures have been observed. On the crown of the left aisle a few weathered patches with fractures can be seen.

The floor of the central hall has been left uneven with the digging of four pits (3 circular and 1 irregular) about 50 –60 cm deep. A few category III fractures, squeeze up structure and trace of unit contact can be seen on the crown of the central hall.

No cracks could be observed within the shrine. On the walk way around the shrine, trace of unit contact and a few minor cracks can be seen.

The outer 4-6 m of the cave may have contained some structure, which has perished.

Grade II weathering is seen on both floor & crown. Damages to sculptures are due to weathering and breakage along minor cracks. Some of the sculptures have started to lose sharpness or detail.

Seepage of water in the cave is restricted to the outer beam where the rock is moderately weathered (Grade III).

The façade of cave 14 can be divided into 3 zones. The lower most zone just above the crown of the cave, consists of moderately weathered basalt. The middle part shows development of negative slope due to differential weathering along a highly fractured zone. Water seepage is observed

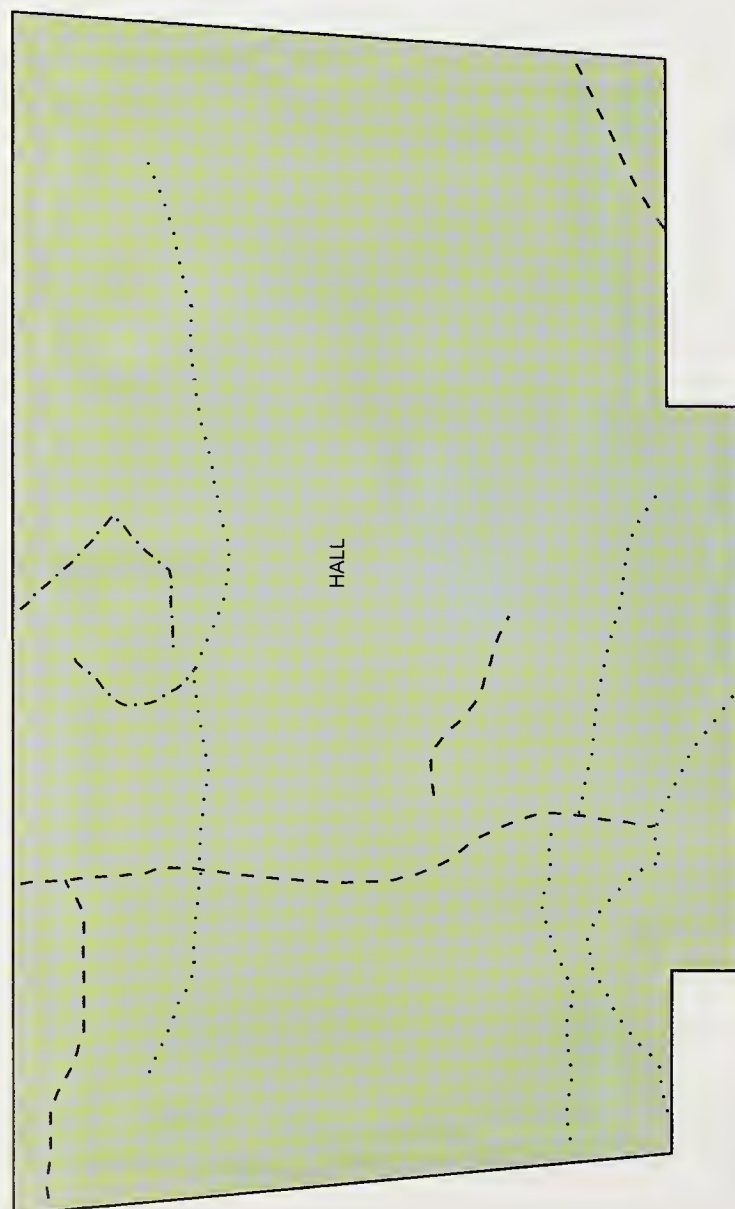


Plate : VII-83

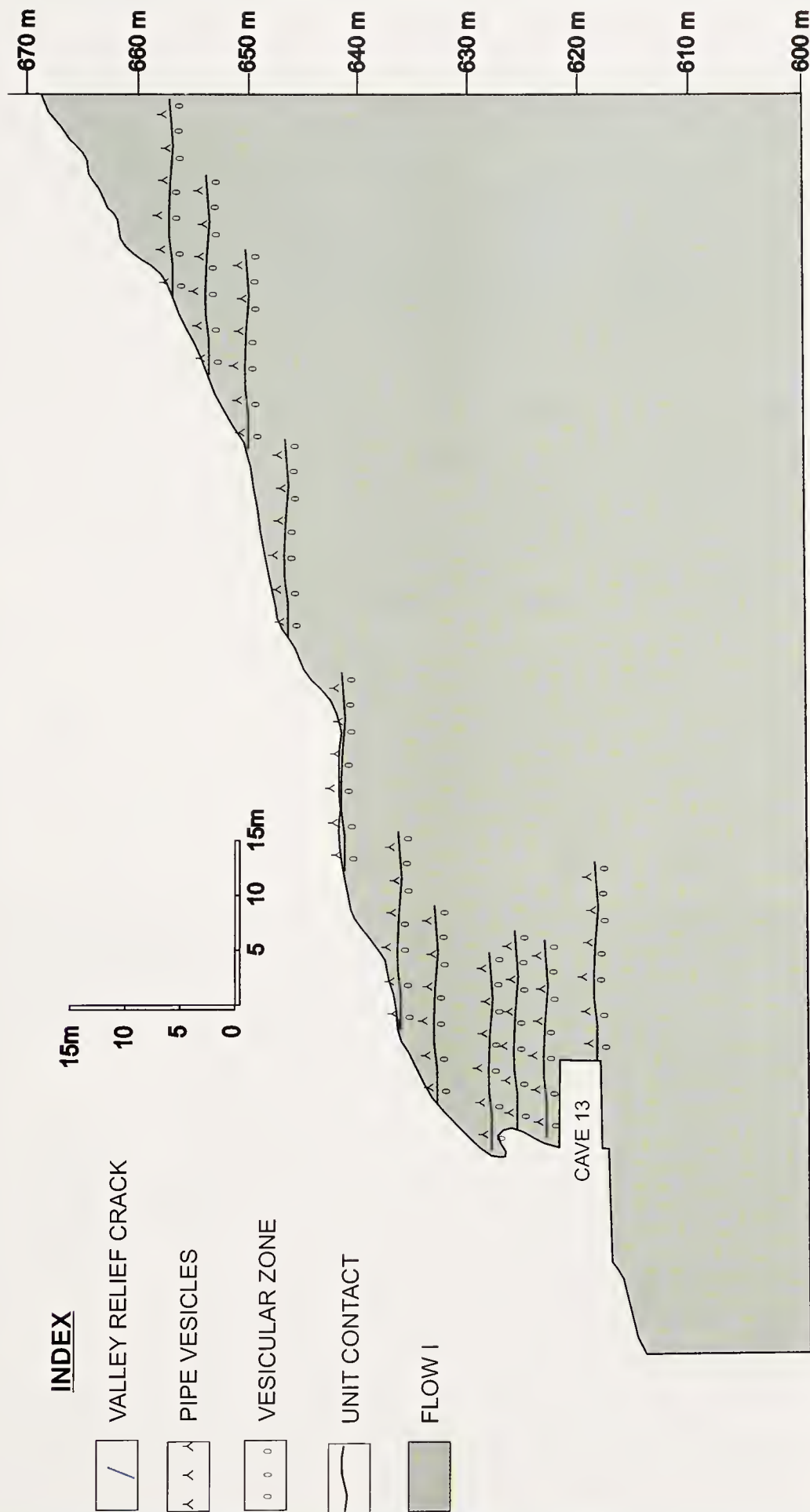
GEOLOGICAL LOG OF CROWN OF CAVE 13 AT ELLORA

INDEX

	SLIGHTLY WEATHERED VESICULAR BASALT
	TRACE OF CRACKS/FRACTURES
HAZARD GRADATION OF CRACKS	
	CATEGORY I
	CATEGORY II
	CATEGORY III
	CATEGORY IV
	CATEGORY V
	STABLE, HAIRLINE
	UNSTABLE AREAS WHERE TREATMENT IS REQUIRED
R. L. OF FLOOR: 620.67 m	
R. L. OF CROWN: 624.47 m	
SHEETS: 1	
MAPPED BY: Dr. C. Joshi Geologist Jr.	



GEOLOGICAL CROSS SECTION ALONG THE CENTRE LINE OF CAVE 13 AT ELLORA





through the fractured zone due to infiltration from the ground surface (where the fractured zone crops up). Above this lies the moderately weathered basalt.

On the roof of the cave, water from a nala is directed to the side of the cave by a channel. This channel is blocked at the end and results in ponding of water, which then overflows over the façade.

Treatment measures suggested are as follows:

- 1) Reinforced shotcrete with provision of drainage holes in the negative slope above caves 13 & 14.
- 2) Plain shotcrete below cave 13 and above caves 13& 14.
- 3) Shotcrete to be extended for 20 m on top. Top drain to be constructed and end of shotcrete discharge to be led to nala above 14.
- 4) Training & lining of nala

The geological log of the crown of cave 14 is presented in plate VII – 85 and section along the centerline of cave is presented in plate VII - 86 respectively.

CAVE - 15

Cave 15 is situated at a higher level and is approached by a flight of steps and through a rock cut gateway. Outside the entrance on the left side is a small cell. There are no fractures on the crown of the cell but the walls show numerous cracks. Weathering has taken place along a unit contact.

Inside the cave complex is a courtyard with a square 'mandapa' in the center. Immediately after the entrance there are two cells on either side of

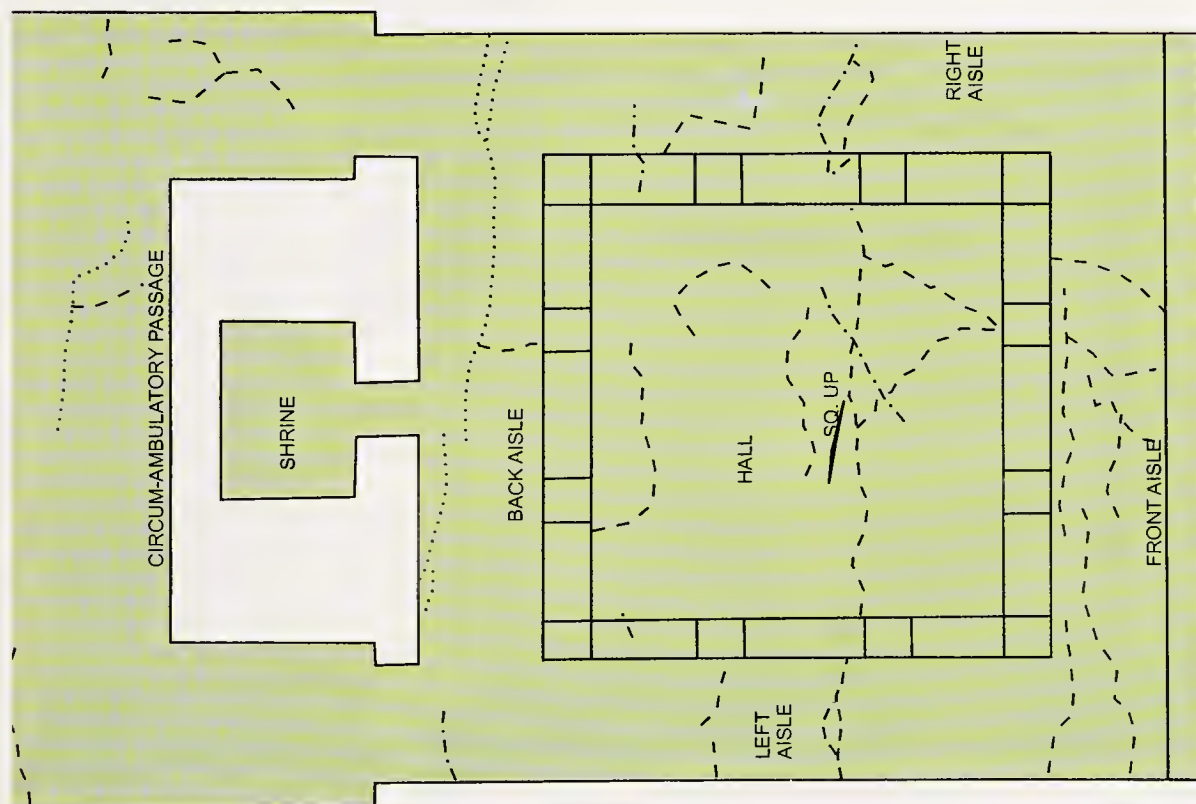
the 'mandap' on the walls of the courtyard. The cell on the left has a shrine inside. A category II fracture and another category V fracture can be seen on the crown. The latter also shows water seepage. The seepage is in the form of droplets. On the cut face above the cell a unit contact is seen with a slight slope towards east. Above the unit contact the rock is moderately weathered and covered with a soil zone. The westerly dipping highly fractured zone cuts across the unit contact. The water that is collected in this soil - weathered rock zone is transported downwards along the highly fractured zone and then eastwards along the unit contact and seeps into the cell through the vertical crack.

The cell on the right has almost entirely perished, with most of the crown and sidewalls having fallen.

The 'mandap' in the center of the courtyard consists of a central hall & four surrounding aisles. The rock on the crown is moderately weathered and flaking at places. Unit contact can be seen at a height of about 90 cm. Pipe amygdules are visible.

On the right wall of the courtyard is a complex consisting of water tanks and a cell situated above. The crown of the cell is highly fractured and at a few places the rock has collapsed. The water seepage is in the form of droplets. The cover of the rock over the crown is very thin and the rock is moderately (Grade-III) to highly weathered (Grade IV). Surface treatment in the form of placement of an impervious layer over the crown may have to be resorted to, to arrest water seepage. A portion of the floor of the cell has collapsed into the water tank below.

The facade of cave 15 which is a double decked cave is marred by rock collapse & weathering.



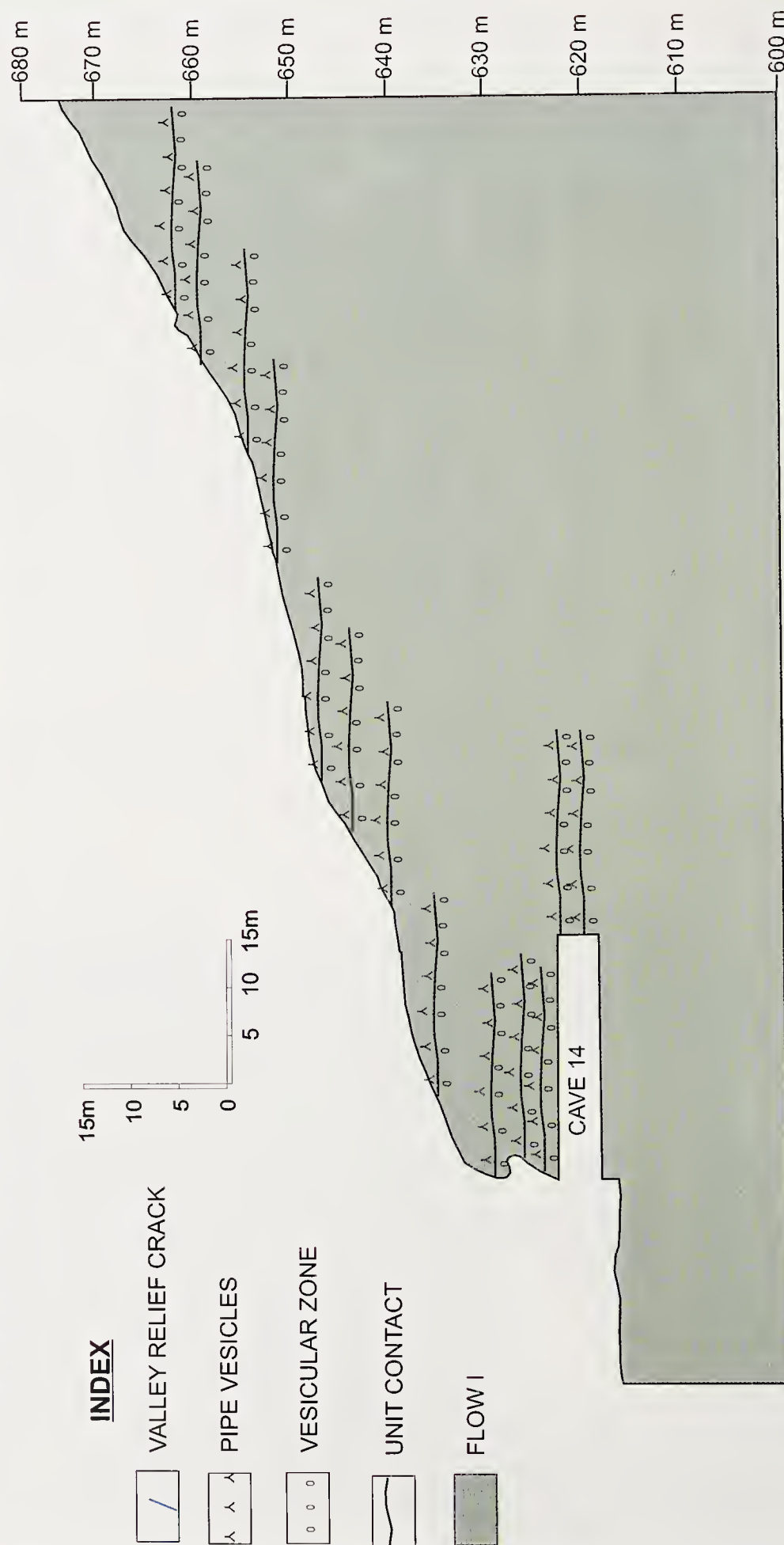
INDEX

	SLIGHTLY WEATHERED VESICULAR BASALT
	TRACE OF UNIT CONTACT / SQUEEZE UPS
	TRACE OF CRACKS / FRACTURES
	WATER SEEPAGE ZONES
HAZARD GRADATION OF CRACKS	
	CATEGORY I STABLE, HAIRLINE
	CATEGORY II
	CATEGORY III
	CATEGORY IV
	CATEGORY V UNSTABLE AREAS WHERE TREATMENT IS REQUIRED
R. L. OF FLOOR: 619.96 m	
R. L. OF CROWN: 624.10 m	
SHEETS: 1	
MAPPED BY: Dr. C. Joshi Geologist Jr.	



Plate : VII-86

GEOLOGICAL CROSS SECTION ALONG THE CENTRE LINE OF CAVE 14 AT ELLORA





The highly fractured zone cuts across the façade. The lower deck consists of a T shaped hall divided into three parts by a row of pillars. On either side are two cells. Minor cracks, traces of squeeze up structures and geodes can be seen on the lower deck.

A cell on the left side with a stairway leads to the upper deck. Unit contact occurs at the level between two decks. In the upper deck unit contact is seen at a height of 1 m. Pipe amygdules are present. Traces of another unit contact are seen on the crown of the upper deck. Remnants of paintings are seen. Minor fractures are present.

The upper deck is much larger than the lower deck. The upper deck is divided into 7 aisles by rows of pillars. An antechamber & shrine are present. On the upper deck water seepage is seen in the form of moist patches/droplets near the 2nd pillar of the 5th beam.

Grade III to IV weathering is seen in the rock on either side of the flight of steps outside the cave. Grade III weathering is seen near the entrance while Grade II weathering is seen in the 'mandap'. The rock inside the cave is fresh and unweathered. Damage to sculptures is due to minor cracks along which some portions have collapsed.

Water seepage is restricted to the façade and is through the highly fractured zone. The basalt exposed on the façade shows exfoliation weathering. The cover over the cave is thin. The likely infiltration zones lie east of the cut face of the cave, where the highly fractured zone is likely to crop out. Immediately behind the cut face of cave lies the foot track to Khultabad. On the eastern side of the foot track is a drain, which contributes to the water seepage in cave 15. Proper lining of this drain will reduce water seepage to the cave.

Treatment measures to be adopted include the following:

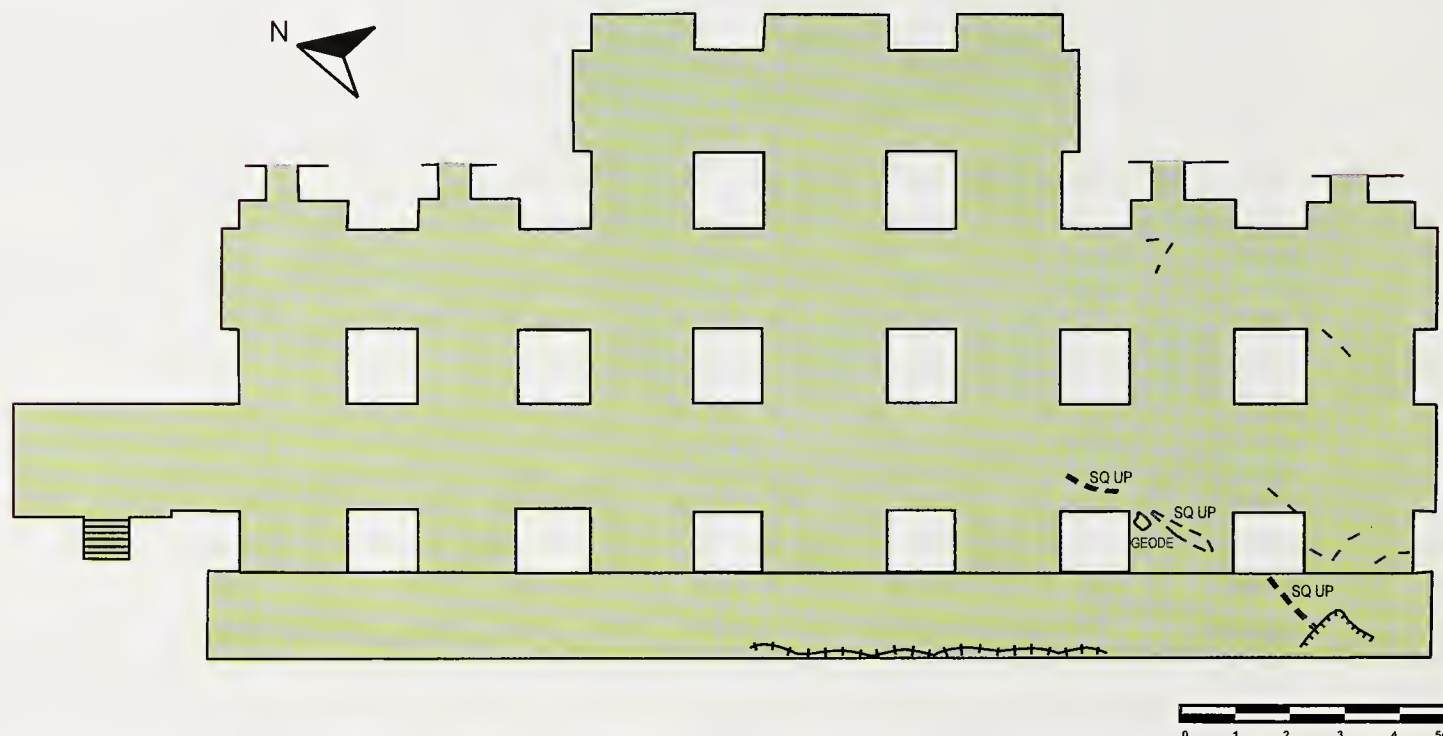
- 1) Boulder packing and plain shotcrete on the rock ledge on both sides of the staircase near and outside the entrance.
- 2) Shotcreting of the façade to increase strength, with provision of drainage holes.
- 3) Extending the shotcrete along the hill slope up to the foot track to Khultabad.
- 4) Existing drain situated on the up-slope side of the foot-track to be cleaned widened and lined.
- 5) All the drains should be embedded in fresh bedrock and windows to be left on the hill slope side to collect seeping water.

The geological log of the crown of cave 15 is presented in plate VII – 87, 88, & 89 and section along the centerline of cave is presented in plate VII - 90.

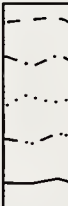
CAVE 16

Cave 16, which is known as the 'Kailash' – Lord Shiva's mountain abode is the largest and the best of all Ellora excavations and is, considered to be the finest monument in India. The world's greatest monolithic structure, Kailash combines immensity with grace, energy and sheer genius. It has been estimated that approximately 3,000,00 cubic feet of rock has been excavated, a task estimated to have taken over a hundred years. The Kailash temple itself was constructed by King Krishna I, of the Rashtrakut dynasty in 760 AD. The work of excavation was started from the top. A deep rectangular trench 32m deep was dug leaving an enormous block in the center, which was then chiseled into the Shiva temple as we see it today (Plate VII – 103).

GEOLOGICAL LOG OF CROWN OF LOWER DECK **OF CAVE 15 AT ELLORA** SHEET - I



INDEX

	SLIGHTLY WEATHERED VESICULAR BASALT	<u>HAZARD GRADATION OF CRACKS</u>		
	TRACE OF UNIT CONTACT / SQUEEZE UPS		CATEGORY I	STABLE, HAIRLINE
	TRACE OF CRACKS/ FRACTURES		CATEGORY II	
	WATER SEEPAGE ZONES		CATEGORY III	
	PLASTERED CRACKS		CATEGORY IV	
	EDGE OF BROKEN CROWN/ ROCK FALL ZONES		CATEGORY V	
				
			UNSTABLE AREAS WHERE TREATMENT IS REQUIRED	
		SHEETS: 3		

LOWER DECK
R. L. OF FLOOR:625.50 m
R. L. OF CROWN:629.55 m

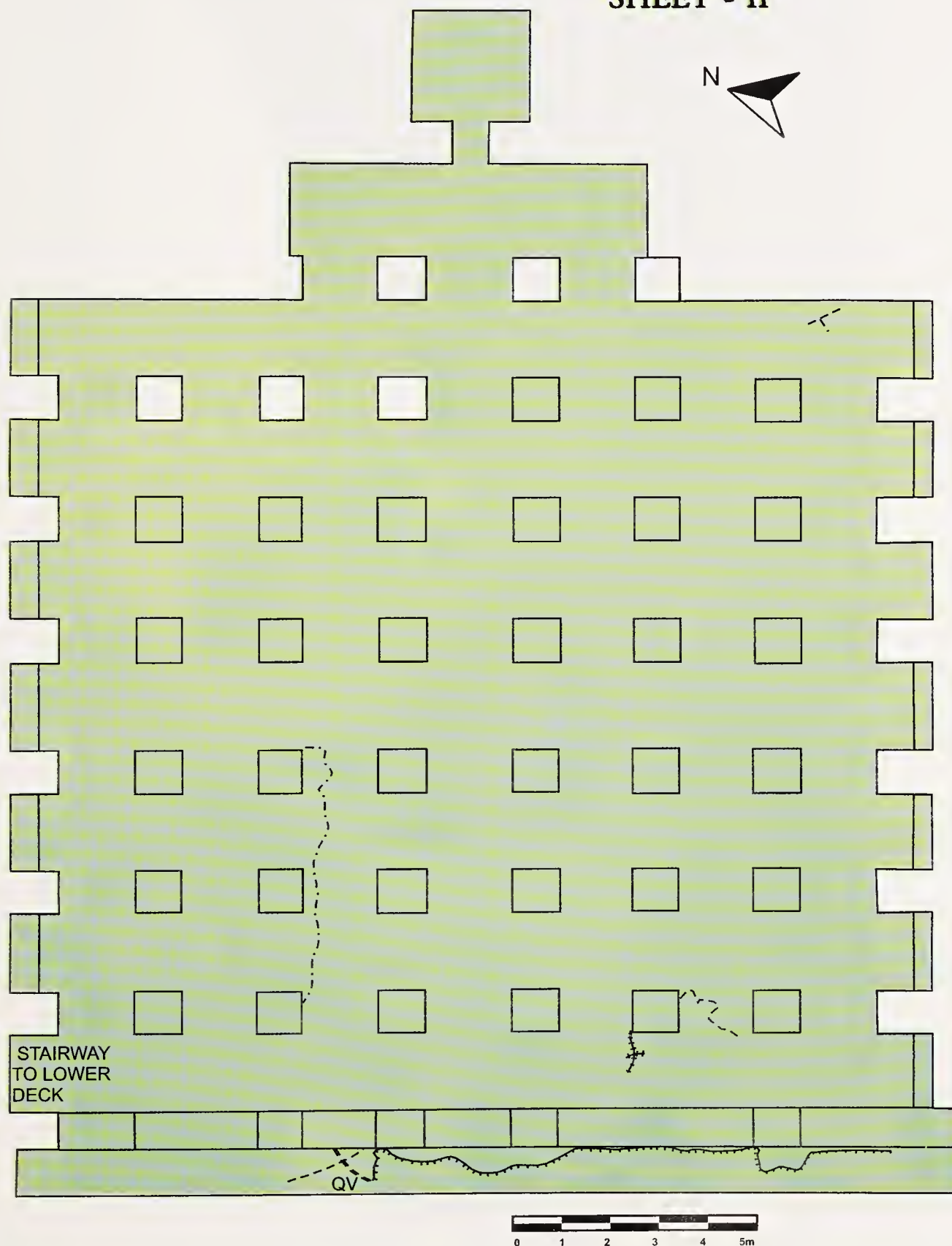
UPPER DECK
R. L. OF FLOOR:631.00 m
R. L. OF CROWN:634.50 m

MAPPED BY: Dr. C. Joshi
Geologist Jr.

Plate : VII-88

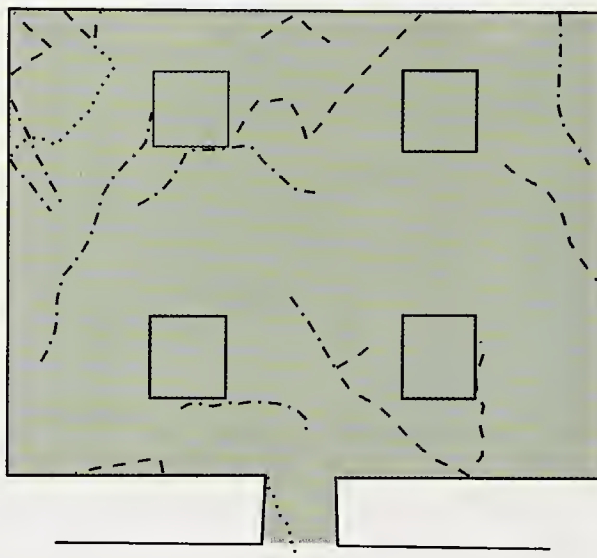
**GEOLOGICAL LOG OF CROWN OF UPPER DECK
OF CAVE 15 AT ELLORA**

SHEET - II

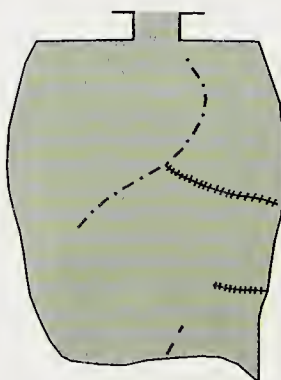


GEOLOGICAL LOG OF CROWN OF CAVE 15 AT ELLORA
SHEET - III

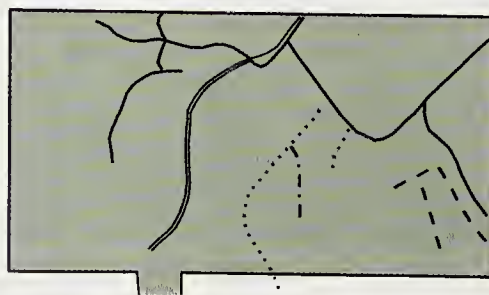
TEMPLE IN COURTYARD



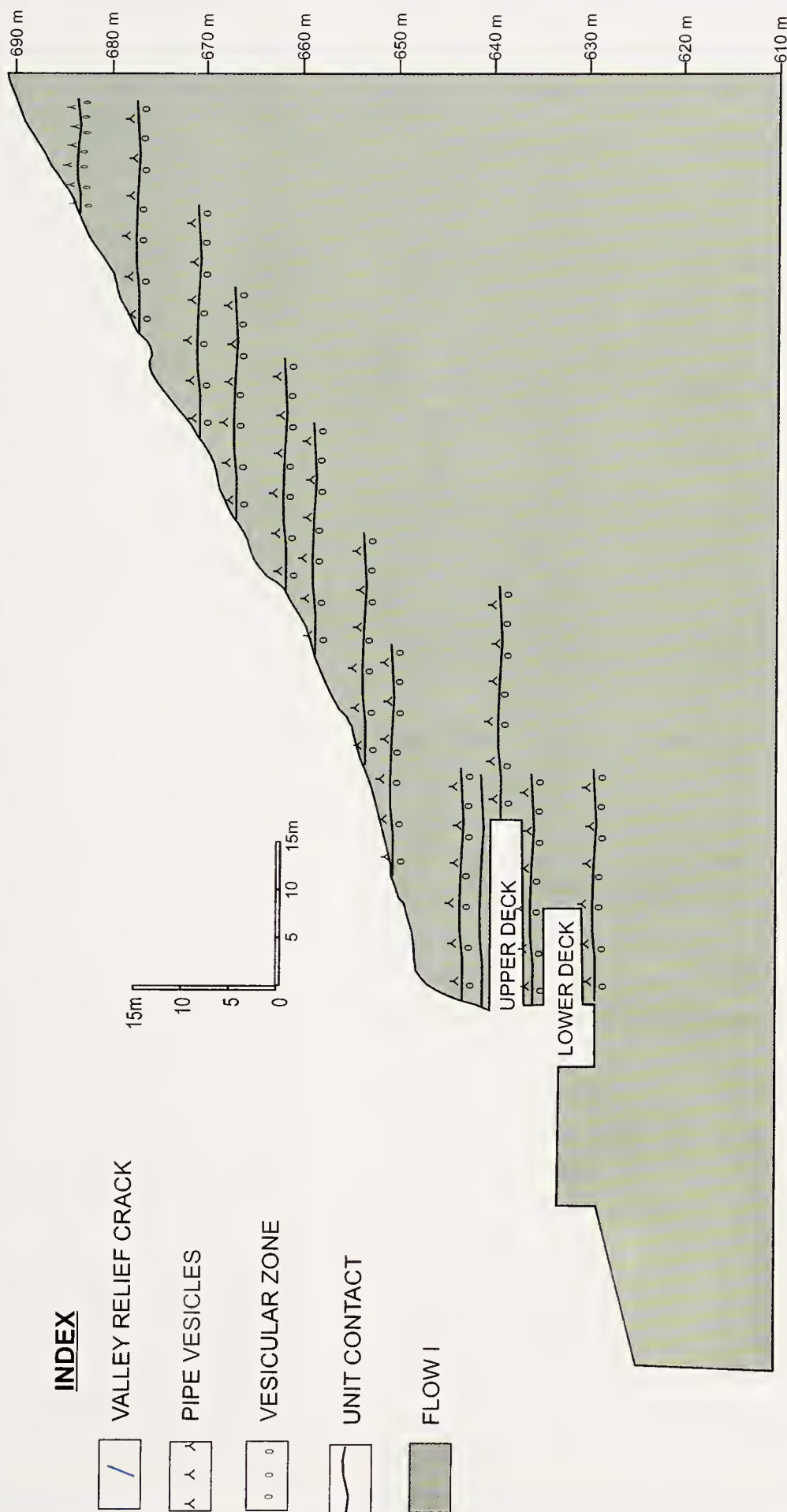
CELL ON LEFT WALL OF THE COURTYARD



CELL ABOVE WATER TANK ON RIGHT WALL OF COURTYARD



GEOLOGICAL CROSS SECTION ALONG THE CENTRE LINE OF CAVE 15 AT ELLORA



The sculptures on the west-facing wall on either side of the entrance appear to have suffered more weathering due to westerly winds and exposure to sun.

On entering cave 16, two pillared porches with inner cells can be seen on either side of the passage. The crown of the pillared porch on the right is plastered and therefore the state of the original rock cannot be ascertained. Inside the cell, one category III fracture can be seen. The crown of the porch on the left is also plastered. In the cell a portion of the crown has perished.

Further inside, the passage leads to a porch, which is open on the sides and contains ornamentation on the back wall. The crown has been partially rebuilt by placing two steel beams and plastering the broken portion.

Excavated on the front wall and approached from the inside is a small cave on the right side of the entrance. The basalt here is highly weathered. Unit contact is seen near the crown and portions of the crown have collapsed along this line. A major portion of the remaining crown has also started to separate. A squeeze up structure can be seen running diagonally across the cell and some rock material has fallen along this creating a 15 cm deep cavity. Numerous other open cracks are present on the crown and walls. Two cement pillars have been built to shore up the crown. Minor cracks are seen in the pillar on the right. The two original pillars show grade III of weathering and have lost strength. On the right side of the entrance and excavated on the front wall of cave 16, is an unfinished excavation. It can be approached from the inside. The basalt is highly weathered. A number of cracks falling in category III are present on the crown.

In between the two staircases leading to the Kailash temple, there is another porch that is also open on the sides and contains ornamentation on the back & front walls. On the crown, one fracture falling in category I, a squeeze up structure that appears to have opened slightly and a quartz vein can be observed. On the walls, unit contact can be seen at a height of 2.4 to 2.8m from the floor. Pipe vesicles can also be observed.

On the left face of the cave opposite the stone elephant is a small verandah with ornamentation on the walls (Images of 'Ganga', Jamuna and Saraswati). The verandah is situated at a height of 1.6m from the level of the open courtyard. Unit contact can be seen on the walls of the verandah at a height of about 50-60 cm from the floor. Pipe vesicles are present. The lower portion of the pillars and walls has been plastered. Squeeze up structures can be seen at one or two places. On the left side of the verandah a sub-vertical fracture can be seen on the wall. The crown shows minor fractures falling in category I. Over this at a higher level another small excavation can be seen. Damages to the sculptures on either side of the steps is extensive due to close proximity to a unit contact, along which weathering is accentuated. Loss of both detail and original form is noticed. In the verandah, the sculptures of Ganga, Jamuna & Saraswati are partly destroyed along a unit contact. Grade II weathering is seen in the rocks inside the verandah, while the rock outside shows Grade III weathering.

Opposite the pillar known as the 'Kirti Stambh' and situated on the left face of the cave, is a small verandah, which leads to a complex on the upper deck (Called 'Chikni Lanka'). Inside the verandah the crown shows minor fractures that fall mostly in category I. At one place excavation of the crown has cut across a vug with zeolite filling.



A small part of the vug has collapsed, creating a gap, which has been plastered. Part of the overhang outside the verandah has perished along a unit contact. The portion adjacent to the collapsed portion has started to open up and may get dislodged at any time. The sculptures on the panel below the outer wall have started to lose sharpness and detail. Five to six meters above this contact another unit contact can be seen. The block between these two contacts has started to separate and may collapse eventually. Steps need to be taken to anchor the block. A flight of steps leads to the upper deck. Most of the crown area is covered by remnants of plaster and paintings. No fracture could be deciphered. The overhang outside the deck has been excavated along a unit contact and appears to be stable.

Beyond this complex, on the left face of the cave there is another verandah and a partially excavated hall on the inside. Minor fractures falling in category I are present on the crown of the verandah. A part of the overhang appears to have perished along a unit contact. The remaining overhang appears to be stable.

The Kailash temple, situated in the center of cave 16, at a higher level, consists of a central hall flanked on three sides by verandahs. The two verandahs on the right and left of the central hall can be approached only from the hall, while the verandah on the front side is approached by flights of steps on either side. On the back wall on either side of the shrine are two doors, which open into a courtyard (backyard ?) where four small temples are situated. Most of the temple is covered by remnants of paintings and plaster. On the crown of the central hall two cracks falling in category I can be seen. In the verandah on the right the outer portion of the floor is broken (Plate VII – 105).

The crown shows two fractures falling in category V. The cracks can be seen on the roof of the cave where they have been concealed in plaster. A bridge from the right verandah of Kailash Temple to the second deck of Pad Lanka has collapsed. The cracks seen in the crown of the right verandah are probably related to the collapse of the bridge. The cracks have divided the crown into three parts. It is understood that the ASI has drawn up plans of reconstructing this bridge. Two RCC pillars have been partially constructed, almost up to the level of the bridge. On the walls of the Kailash Temple notches have been made to anchor the steel beams. In view of the fractures in the crown any extra load imparted by the new structure could result in collapse of the right verandah. Moreover both pillars are anchored over weathered rock. In the left verandah and the front verandah, minor grade I fractures are present.

The stairway leading to the Kailash temple from the right side passes through a cell with a sloping crown. The crown of the cell is fractured at places and shows evidences of water seepage. The stairway from the left side also passes through a cell with a sloping crown. This sloping crown is fractured at many places. The roof of the cell also shows a few fractures. Unit contact is seen at the top of the lower door.

Beyond the front verandah is a small open courtyard leading to what is called the 'Nandi Mandap'. It is a small square shaped hall with four doorways. Most of the area of the walls and crown is covered with remnants of paintings. One minor category I crack is seen in one doorway.

Beyond the 'Nandi Mandap' is another small courtyard, which leads to a gallery situated above the front wall and main entrance of cave 16. The

gallery consists of a hall in the center, opening on all four sides into four halls; one on each side. Almost the complete crown portion of all five halls has been cement plastered and concreted and thus the state of the original crown cannot be ascertained. The hall on the left side leads into a courtyard and a cell situated on the left wall of the cave. The courtyard contains a boundary wall and its floor is cemented. In the cell a flight of steps leads down to a water tank. On the crown of the cell one fracture falling in category I is seen. Above the entrance to the cell, unit contacts can be seen at four levels on the vertical scarp surface. In the hall on the right except for a small patch of original rock, the whole of the crown has been cemented. The hall leads to another courtyard with a boundary wall. In this hall, unit contact is seen at about 50 –60cm from the floor.

Surrounding the Kailash and cut into the scarp is a pathway known as the Parikrama, consisting of a narrow verandah like excavation supported by numerous pillars on three sides and recessed into the scarp. The outer portion beyond the pillars is without any support and forms the overhang. The Parikrama is situated at a higher level than the floor of the open courtyard. Unit contact can be seen at 2 levels on the walls. The crown contains only a few cracks, which are of minor category. A portion of the overhang has collapsed along a unit contact on the right side. Another square block at the right corner has become detached and has already shifted a few millimeters. On the left corner also a portion of the overhang has collapsed. Some portions have become detached and are on the verge of collapse (Plate VII – 104).

On the right face of the cave towards the front is a pillared porch with shrine and attached verandah. This complex is approached by a flight of steps.

Unit contact can be seen on the walls of this complex at two levels. Pipe amygdules filled with green earth and silica are visible. The crown of the porch, the verandah and shrine contain numerous category I & II cracks. The outer portion of the base of the verandah appears to have fallen. To the right of the porch is a rectangular verandah. The central portion of the crown has been cut in the form of an arch. Unit contact and squeeze up structure can be observed. After this complex another pillared porch with numerous carved figures. This is situated at a higher level than the preceding complex. Minor category I & II fractures can be seen on the crown. Beyond this is a small excavation at the level of the courtyard. Category I to III fractures can be seen on the crown.

In the central portion of the right face of cave 16 is a four decked complex. The approach to the lower three decks is from inside the complex while the fourth deck can be approached from the outside. This complex is known as 'Pad Lanka'.

The first (bottom) deck of 'Pad Lanka' consists of a verandah and a partially excavated hall. Numerous fractures can be seen on the crown. Trace of unit contact is also visible.

The second deck of 'Pad Lanka' consists of a verandah and a large hall inside. Only a small curved overhang has been carved at crown level. The floor of the deck extends outwards. The overhang of the top deck serves as the crown for this extended part of the floor. The thickness of the floor is about 1m. In the verandah, trace of unit contact and squeeze up structure can be seen. In the hall, a thin quartz vein is seen on the crown. On the overhang (at the level of the third deck), squeeze up structure quartz vein and minor fractures can be observed. The floor of the second deck may have extended outwards and connected



to the right verandah of Kailash temple as at both ends the rock appears to have been broken. The second deck is approached by a flight of steps of modern origin. On the side of the stairway two pillars have been constructed to support the crown of the first deck. The two pillars have been made using dressed basalt blocks (Plate – 106). At the junction of both the pillars and crown there is a small gap and the load is supported at only one or two points. If the stress increases, the pillars will open up due to a point load and collapse. The gaps should be properly packed to ensure even distribution of load.

The third deck of the complex known as the 'Pad Lanka' consists of a rectangular verandah and an inner hall. In the verandah, a portion of the crown has collapsed along a unit contact. Water seepage appears to have taken place through the unit contact as evidenced by a coating of calcium carbonate/oxalate. At another place in the center of the verandah a small part of the crown has perished along a squeeze up structure. The overhang has a few cracks and appears to be stable.

The verandah leads into a rectangular hall. Four pillars with double arched beams support the crown. The central part of the crown has been cut to form a skylight. Above this is another deck (Fourth deck). The entrance to the fourth deck is from the hill slope on the right side of the cave. The inner hall on the third deck is the most critical / vulnerable part of cave 16. Unit contact is seen at the level of the crown (at the junction of the walls with the crown). Extensive weathering has taken place along the unit contact and heavy water seepage is reported. Apart from this, portions of the crown have collapsed along unit contact. At a few places some portions of the crown are precariously poised. Four pillars having double

arched beams support the weight of the overlying rock mass. All the four beams have developed cracks that are vertical and reach up to the unit contact lying above. All these areas in the third deck of 'Pad Lanka' require immediate treatment (Plate – 106).

The fourth deck of this complex can be approached by the foot track on the right of cave 16, leading to the village of Khultabad. It consists of a square hall the crown of which is supported by four pillars. The center of the floor is cut to provide a skylight to the third deck (Plate – 105). The outer wall of this cave has been reconstructed. A portion of the crown on the front side has been repaired using stone slabs. Inside the hall, unit contact can be seen at a height of about 30 – 60cm. The basalt is highly weathered and fractured. Squeeze up structures and vugs are also present. A decorated boundary wall surrounds this cave. To the right of the boundary wall and to the back the rock has been cut into a vertical scarp 5-6m high. Towards the front a retaining wall has been constructed along the paved foot track. The area between the boundary wall and scarp is thus enclosed and may result in ponding of water although some weep holes have been provided. Along the left side of the foot track a drain has been constructed and this slopes towards cave 16. Just before it reaches the cave it is diverted down slope. This drain collects runoff from a fairly large area along the hill slope. This water then charges the westerly dipping highly fractured zone which in turn feeds the north -easterly sloping weathered unit contact. The water is thus transported into the third deck of Pad Lanka through the southern and western walls.

On the right of cave 16 and approached by the foot track leading to the village of Khultabad is a small & unnumbered cave with a shrine inside.

Unit contact is seen on the walls at height of 1-1.5 m from the floor. Pipe amygdulites are visible. Category III fractures are present on the crown through which water seepage takes place.

To the left side of the cave 16 (cave 16/ 4&5) complex and situated at a higher level and approached by a flight of steps cut into the hill slope are two small caves with shrines, excavated side by side. The caves are in a general state of neglect and in a dilapidated condition.

The treatment suggested is as follows:

- 1) Reinforced shotcrete with rock bolts in the NW corner above the verandah having images of Ganga, Jamuna & Saraswati.
- 2) Removal of loose blocks in the NE corner of the Parikrama.
- 3) Rock bolting of loose blocks in the overhang of the parikrama. (Vertical bolts)
- 4) Removal of the half-constructed pillars in Pad Lanka.
- 5) Rock bolting of rock mass to the east of Pad Lanka (Horizontal bolts)
- 6) Shotcreting of the crown of the verandah on the left of the entrance (on the front wall and approached from the inside.
- 7) Pressure packing of the gap between the pillars and crown of first deck of Pad Lanka
- 8) Removal of the old and crumbling guniting surface on the hill slope on the southern side of the cave and shotcreting the surface.
- 9) Repairing the gunited surface on the northern slope wherever necessary.
- 10) Shotcreting of the excavated area to the east of the eastern cut face. Smoothing of the

ground with a gradient towards south to drain the water.

- 11) Treatment of the drain carrying water along the hill slope by lining of the channel and diversion of the channel down slope through a steel pipe to stop infiltration.
- 12) For caves 16 A, B, C:
 - A) Surface shotcrete extending up to 5 m from the top till the base of the scarp.
 - B) Providing a drain at the base of the scarp all along to divert the collected water to the nala north of the cave
 - C) Diverting flow towards the northern part of the nala by filling up the depressions.

The geological log of the crown of Cave 16 is presented in plates VII – 91, 92, 93, 94, 95, 96, 97, 98, 99, 100, 101 and 102.

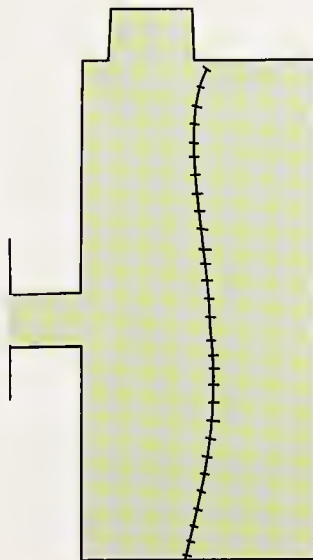
CAVE 17 A

This cave is situated in the north of cave 16 and consists of a courtyard, hall, and shrine. There is a cell to the left of courtyard. Two pillars present on the right of courtyard have developed number of cracks and are in weathered condition. In left side cell, cracks of category IV and V are observed in three pillars and crown portion. Heavy seepage and evidence of rock fall is observed inside this cell. A masonry column has been constructed to prevent rock fall and to act as roof support to sustain the rock load. This rock mass in the cell is highly weathered (Gr.IV) due to seepage of water. The facade above this cell is also slightly weathered (Gr.II) and has developed horizontal open cracks. Seepage in form of continuous dripping is observed from these cracks. The pillars and roof need treatment to avoid any further damage. On the front wall of cave near left cell a horizontal crack

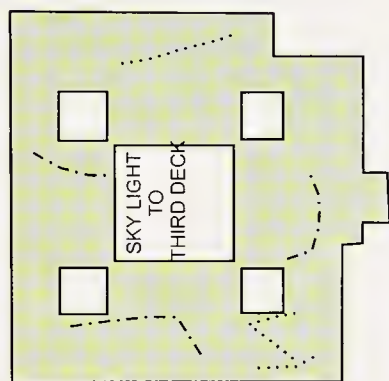
GEOLOGICAL LOG OF CROWN OF PARTS OF CAVE 16 AT ELLORA

SHEET - I

CAVE 16/3 LOCATED NORTH OF CAVE 16

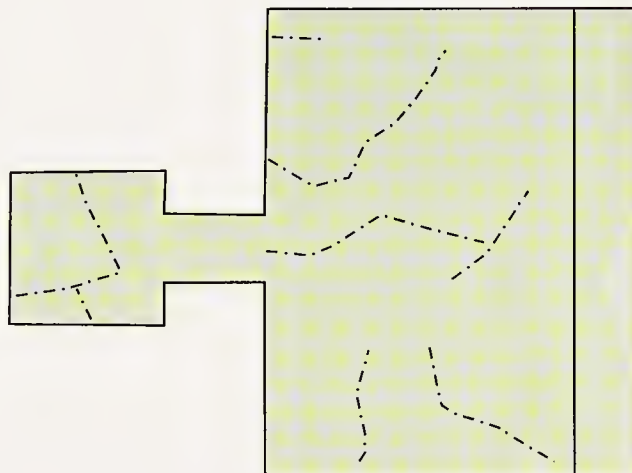


FOURTH DECK OF PAD LANKA

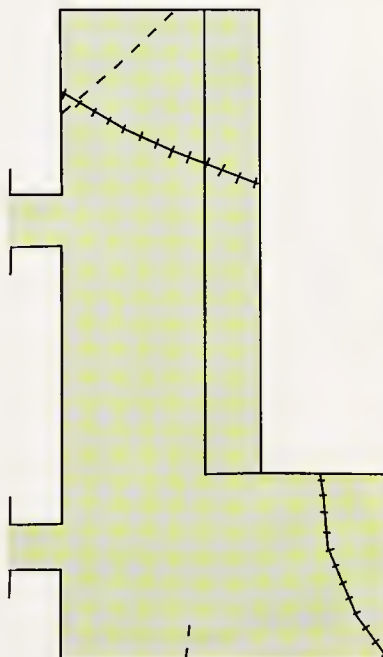


SKY LIGHT
TO
THIRD DECK

CELL & SHRINE ON HILL SLOPE
SOUTH OF CAVE 16



CAVE 16/4&5 LOCATED TO THE NORTH OF CAVE 16



INDEX

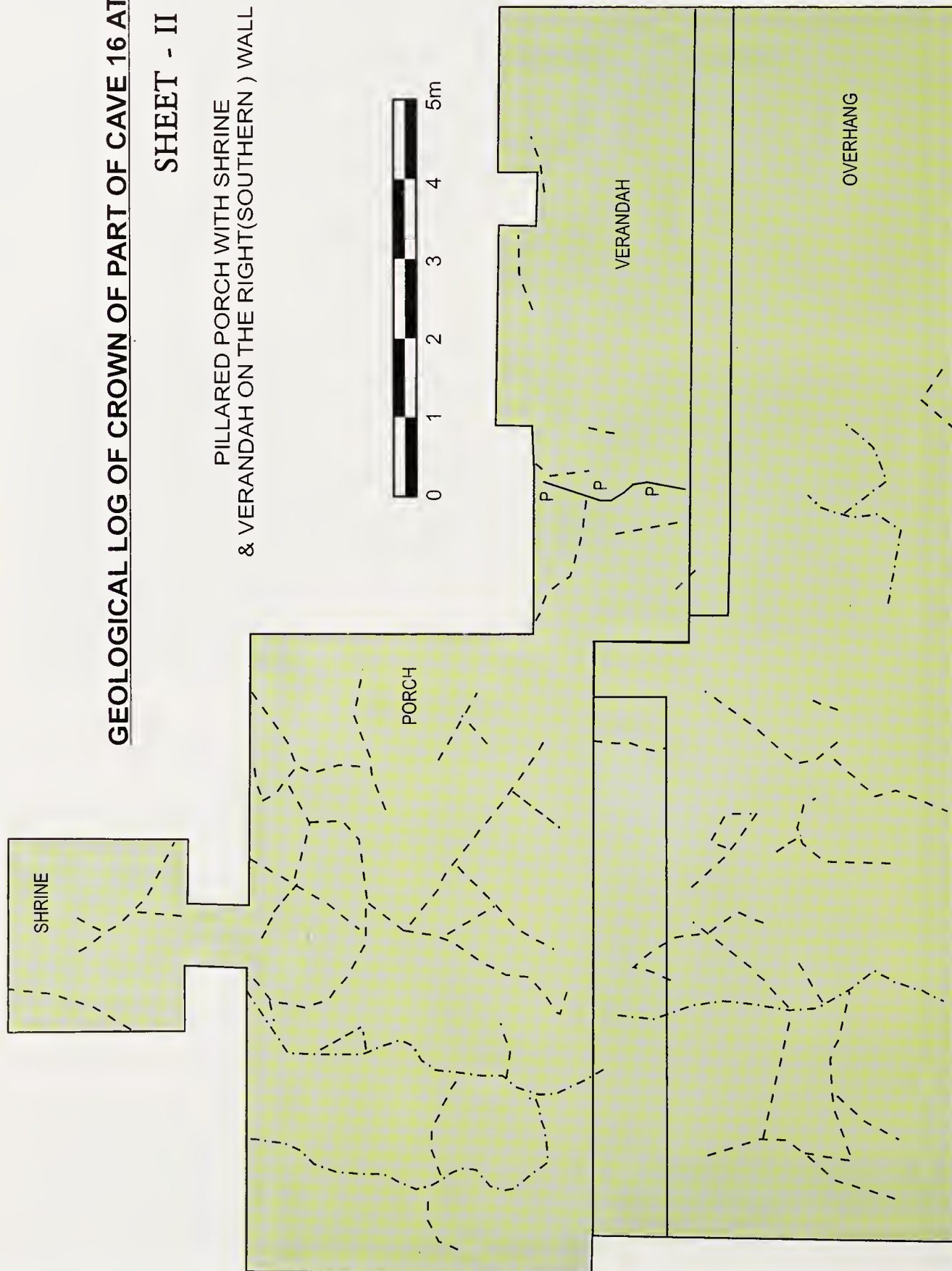
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	TRACE OF CRACKS / FRACTURES
	WATER SEEPAGE ZONES
HAZARD GRADATION OF CRACKS	
	CATEGORY I STABLE, HAIRLINE
	CATEGORY II
	CATEGORY III
	CATEGORY IV
	CATEGORY V UNSTABLE AREAS WHERE TREATMENT IS REQUIRED
R. L. OF FLOOR: 619.96 m R. L. OF CROWN: 624.10 m SHEETS: 12	
MAPPED BY: Dr. C. Joshi Geologist Jr.	

Plate : VII-92

GEOLOGICAL LOG OF CROWN OF PART OF CAVE 16 AT ELLORA

SHEET - II

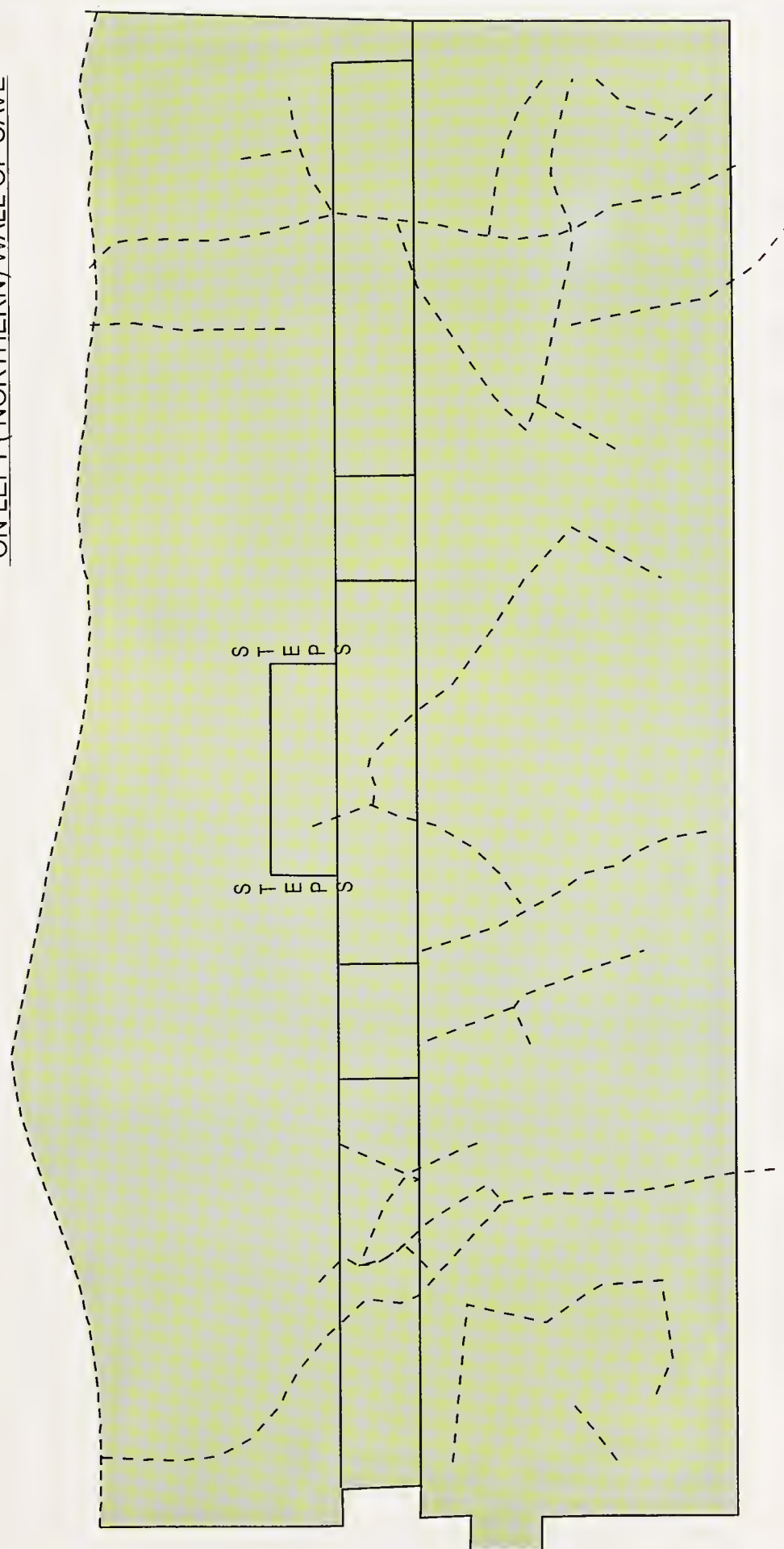
PILLARED PORCH WITH SHRINE
& VERANDAH ON THE RIGHT(SOUTHERN) WALL



GEOLOGICAL LOG OF CROWN OF PART OF CAVE 16 AT ELLORA

SHEET - III

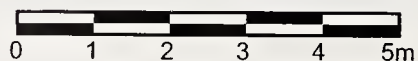
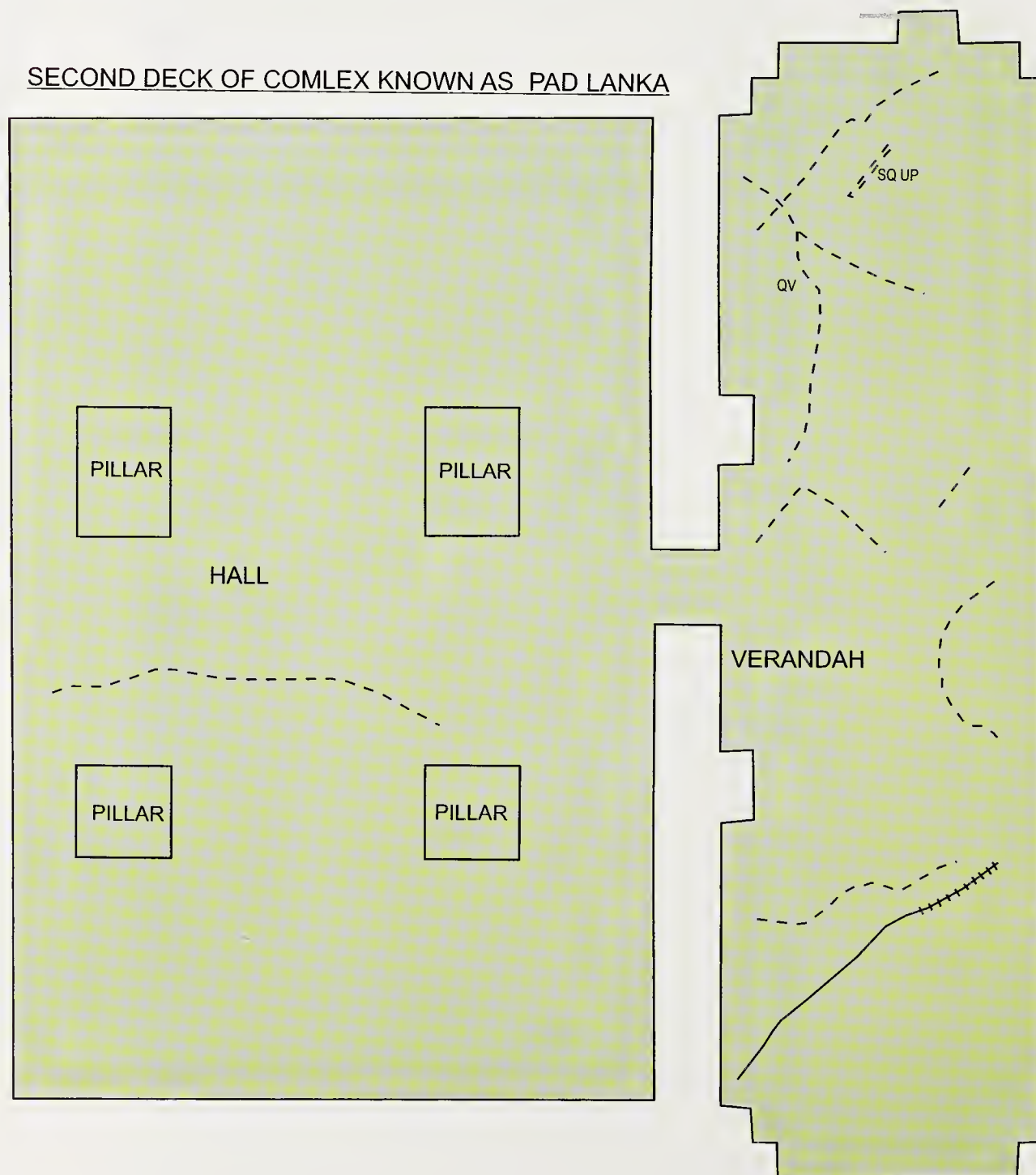
VERANDAH & SMALL UNFINISHED EXCAVATION
ON LEFT (NORTHERN) WALL OF CAVE



GEOLOGICAL LOG OF CROWN OF PART OF CAVE 16 AT ELLORA

SHEET - IV

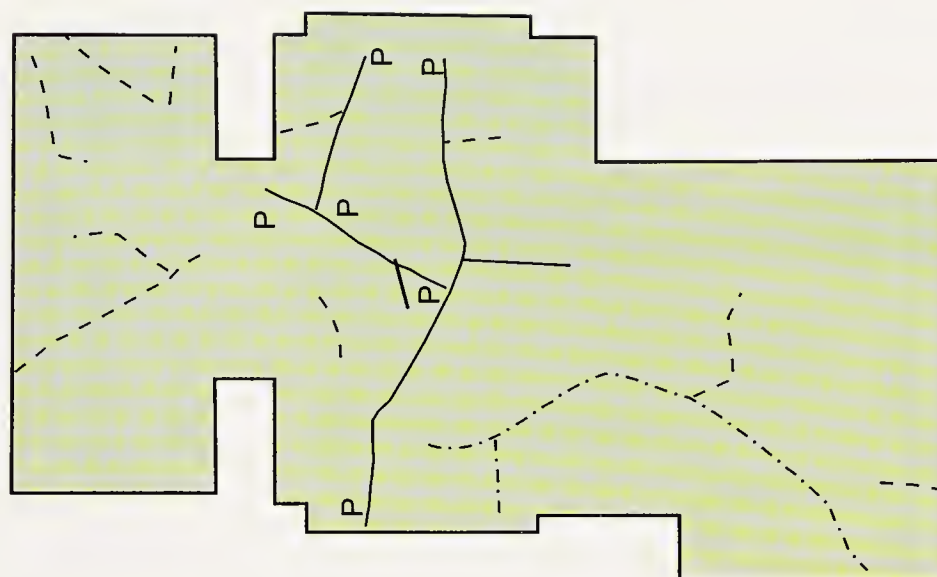
SECOND DECK OF COMPLEX KNOWN AS PAD LANKA



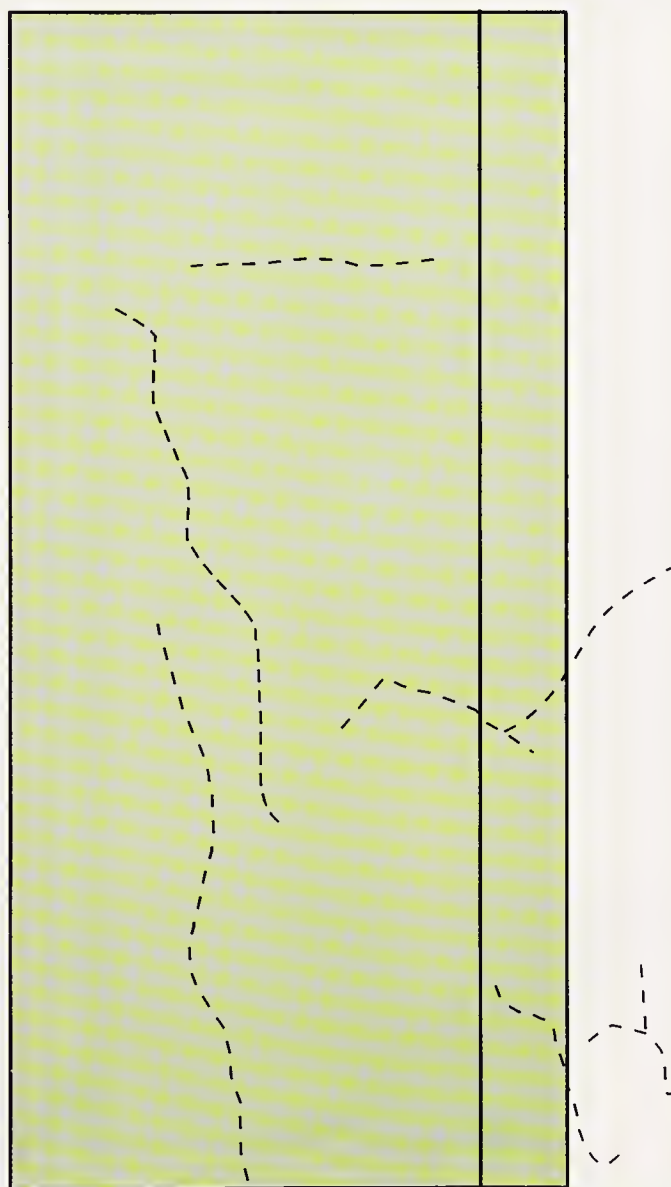
GEOLOGICAL LOG OF CROWN OF PART OF CAVE 16 AT ELLORA

SHEET - V

THIRD PORCH & CELL ON RIGHT SIDE
OF TEMPLE COMPLEX



SECOND PORCH ON RIGHT SIDE OF TEMPLE COMPLEX

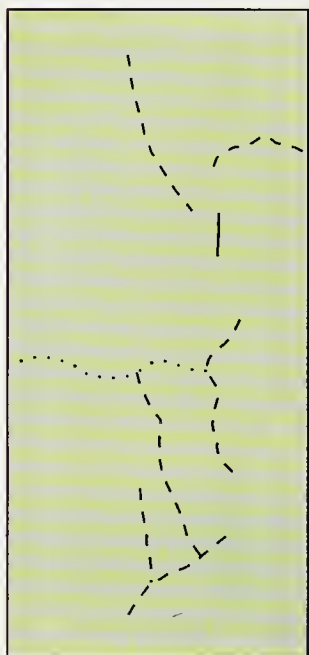




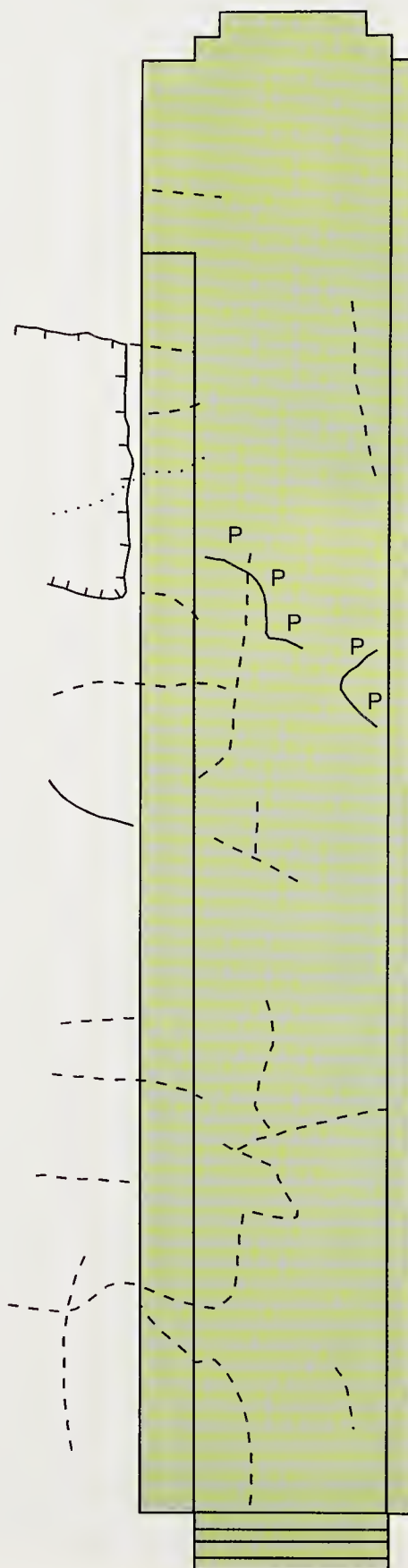
**GEOLOGICAL LOG OF CROWN OF
PART OF CAVE 16 AT ELLORA**

SHEET - VI

FIRST VERANDAH ON LEFT
(NORTHERN WALL)

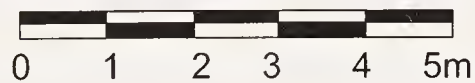
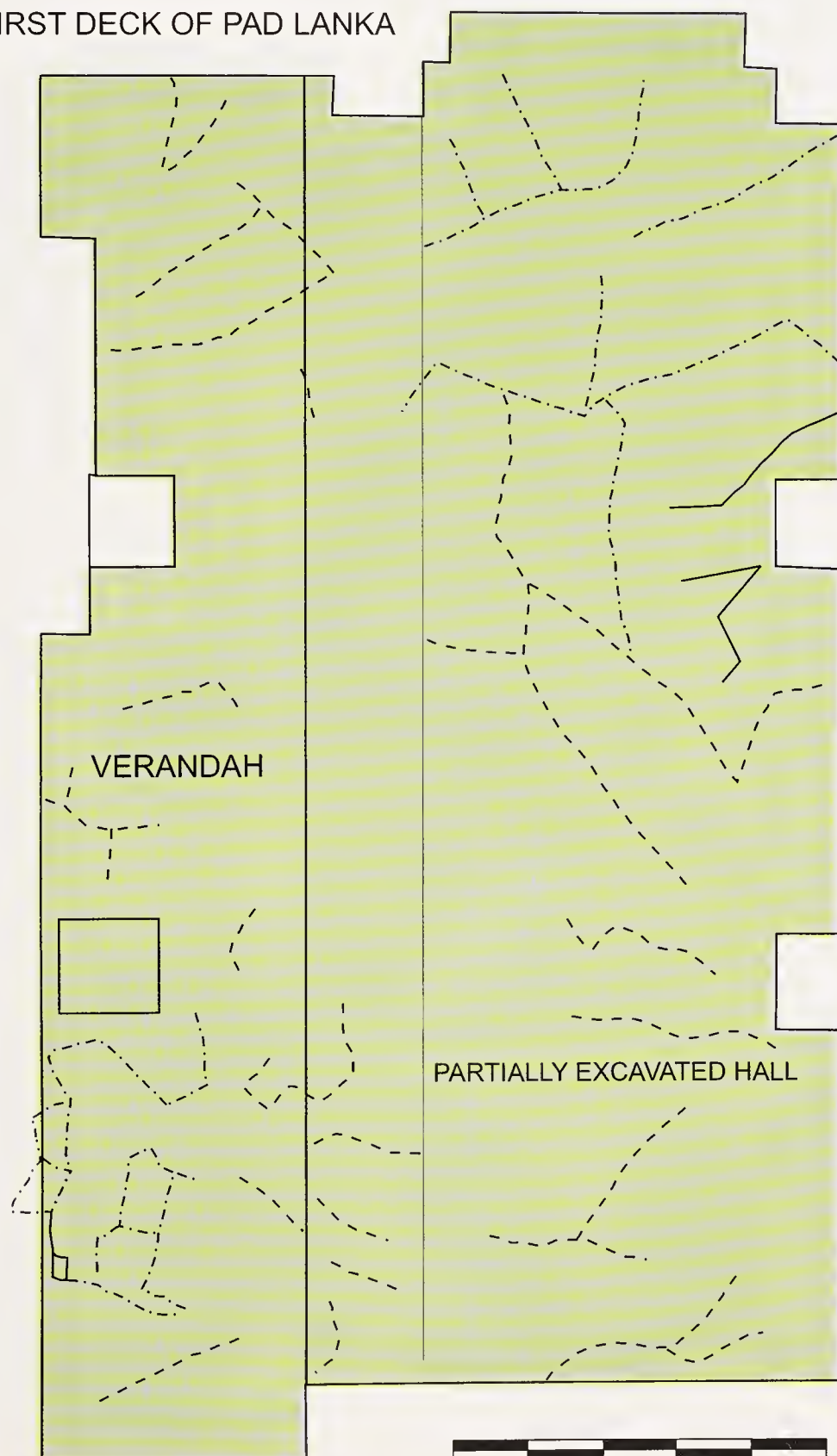


SECOND VERANDAH ON
LEFT(NORTHERN) WALL



GEOLOGICAL LOG OF CROWN OF PART OF CAVE 16 AT ELLORA
SHEET - VII

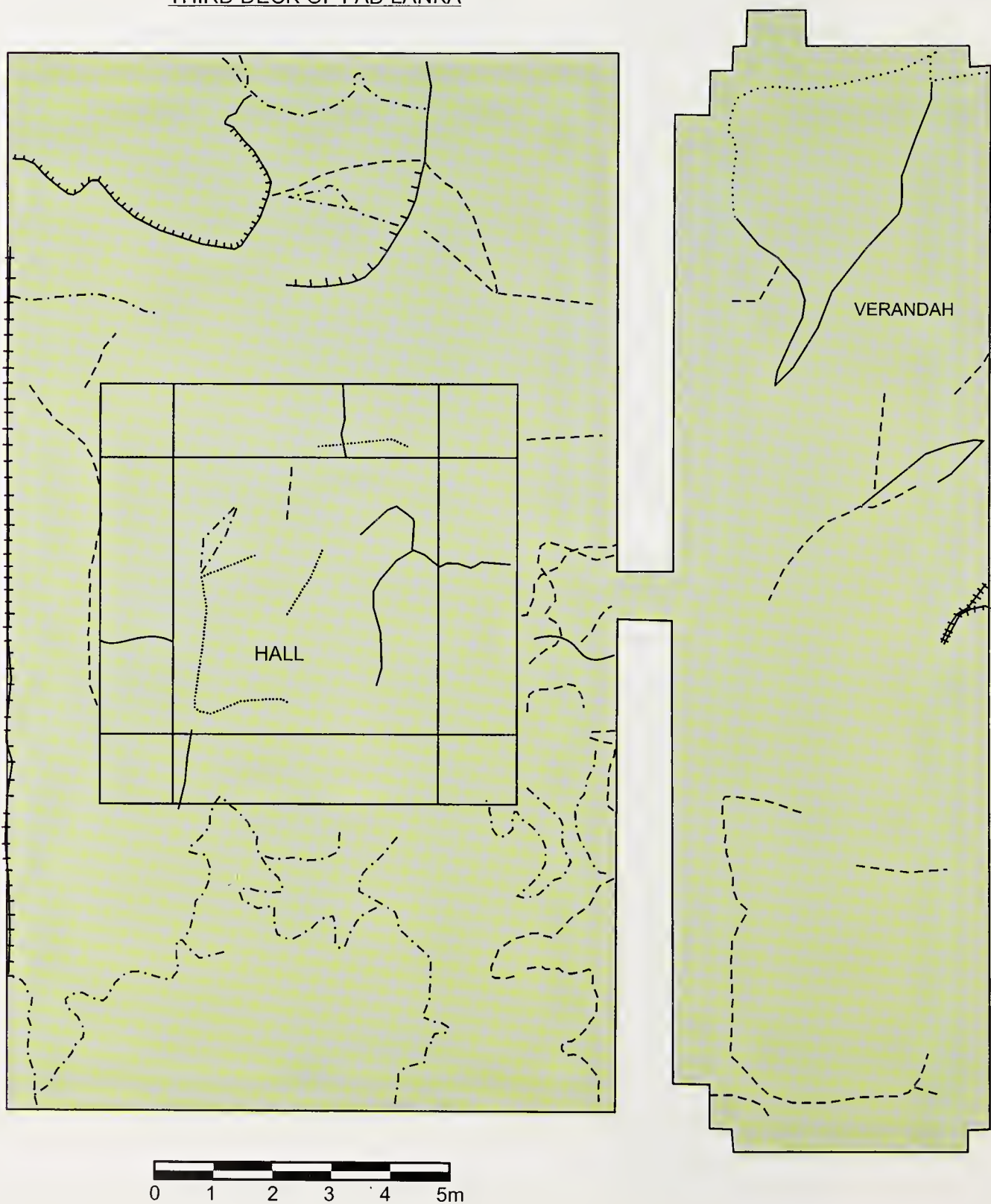
FIRST DECK OF PAD LANKA



GEOLOGICAL LOG OF CROWN OF PART OF CAVE 16 AT ELLORA

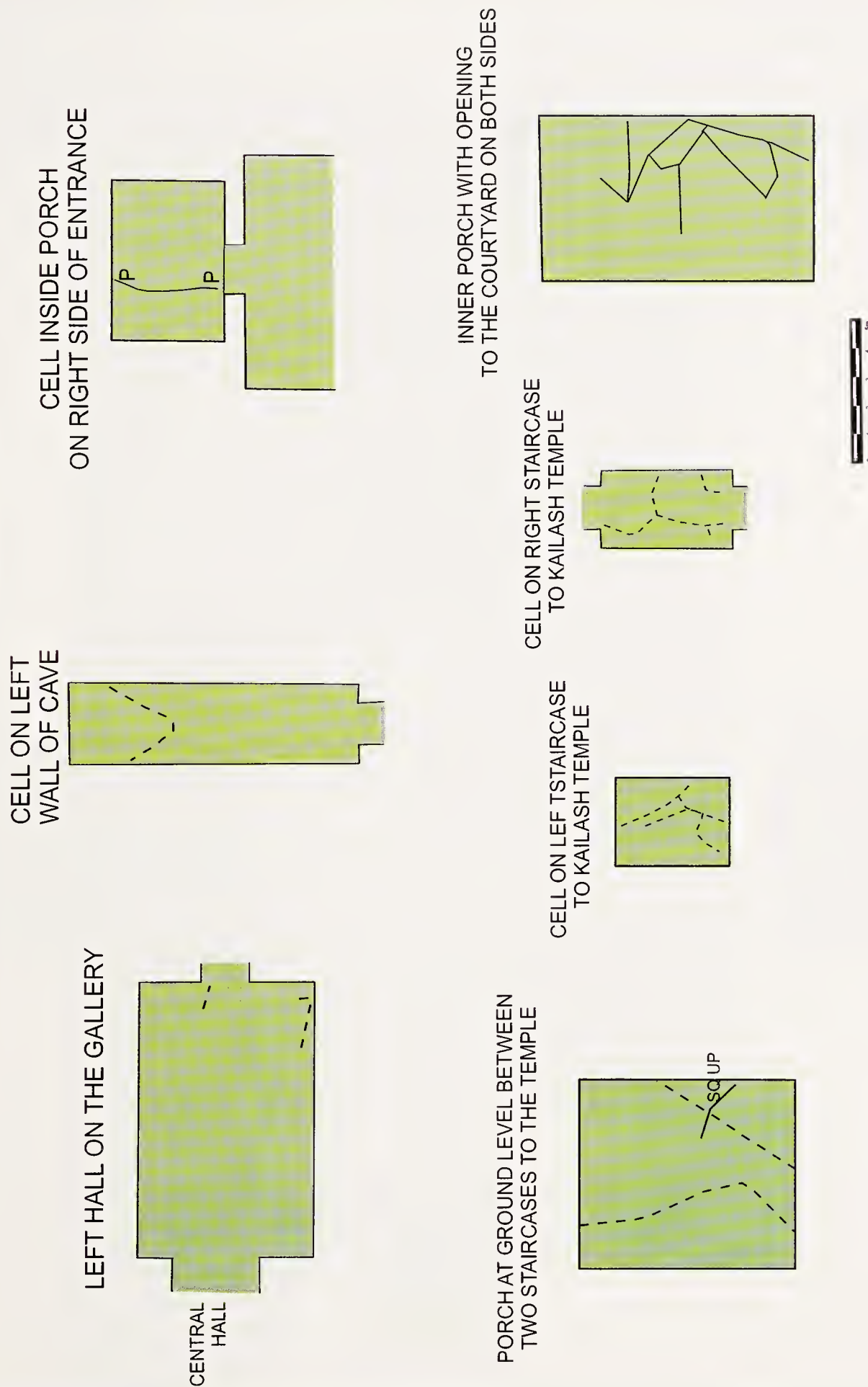
SHEET - VIII

THIRD DECK OF PAD LANKA



GEOLOGICAL LOG OF CROWN OF PART OF CAVE 16 AT ELLORA

SHEET - IX



GEOLOGICAL LOG OF CROWN OF KAILASH TEMPLE AT ELLORA

SHEET - X

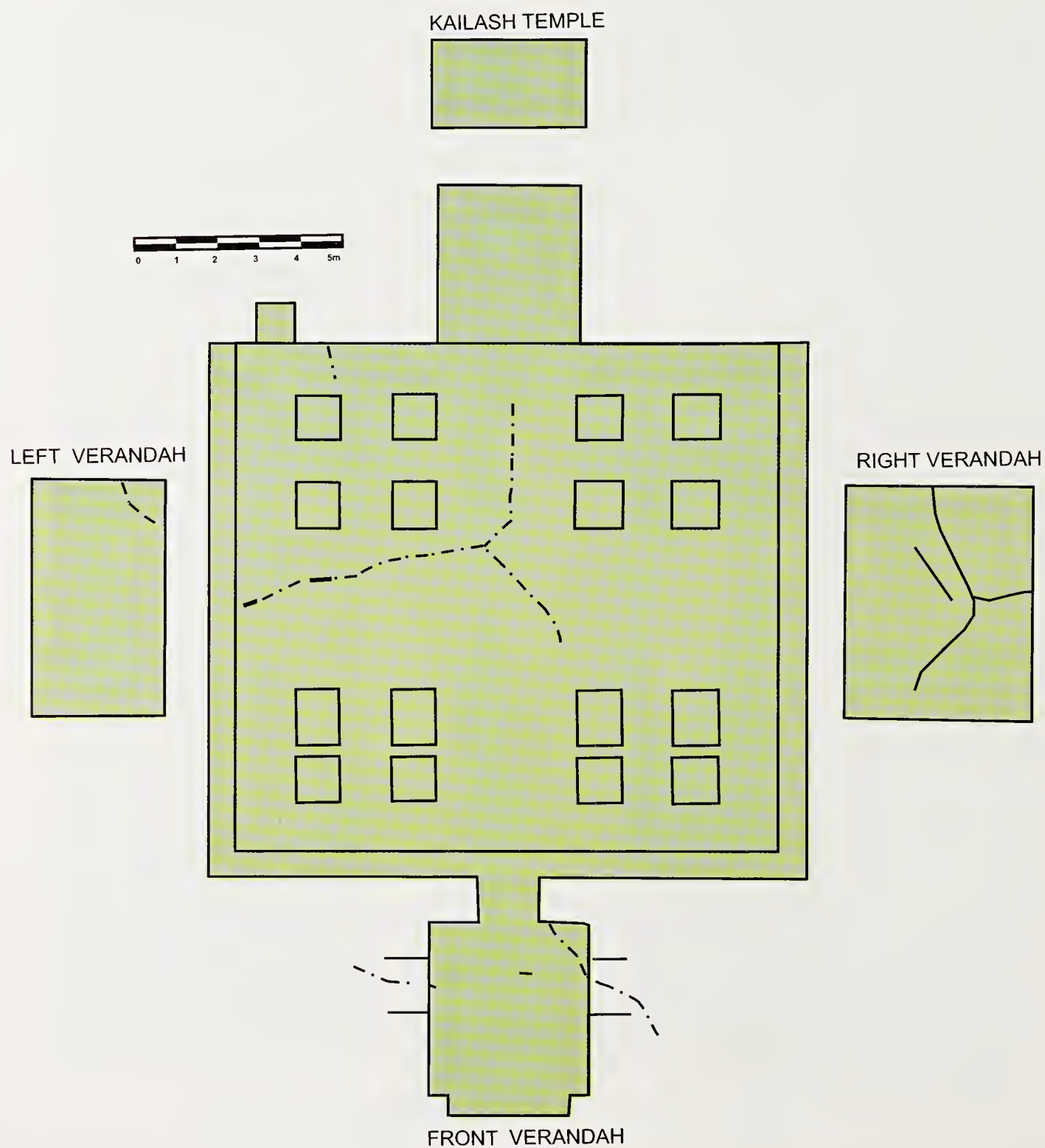
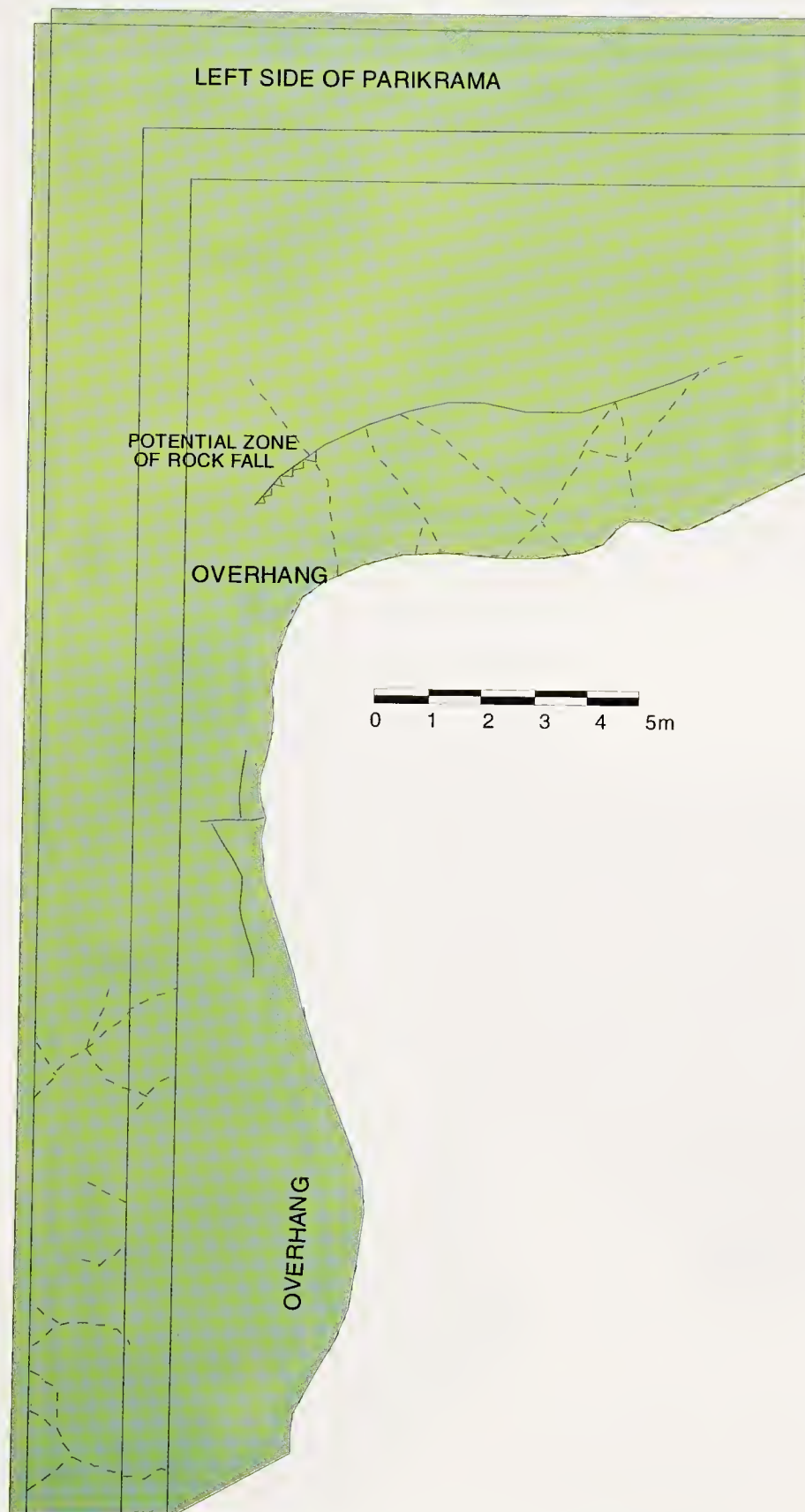




Plate : VII-101

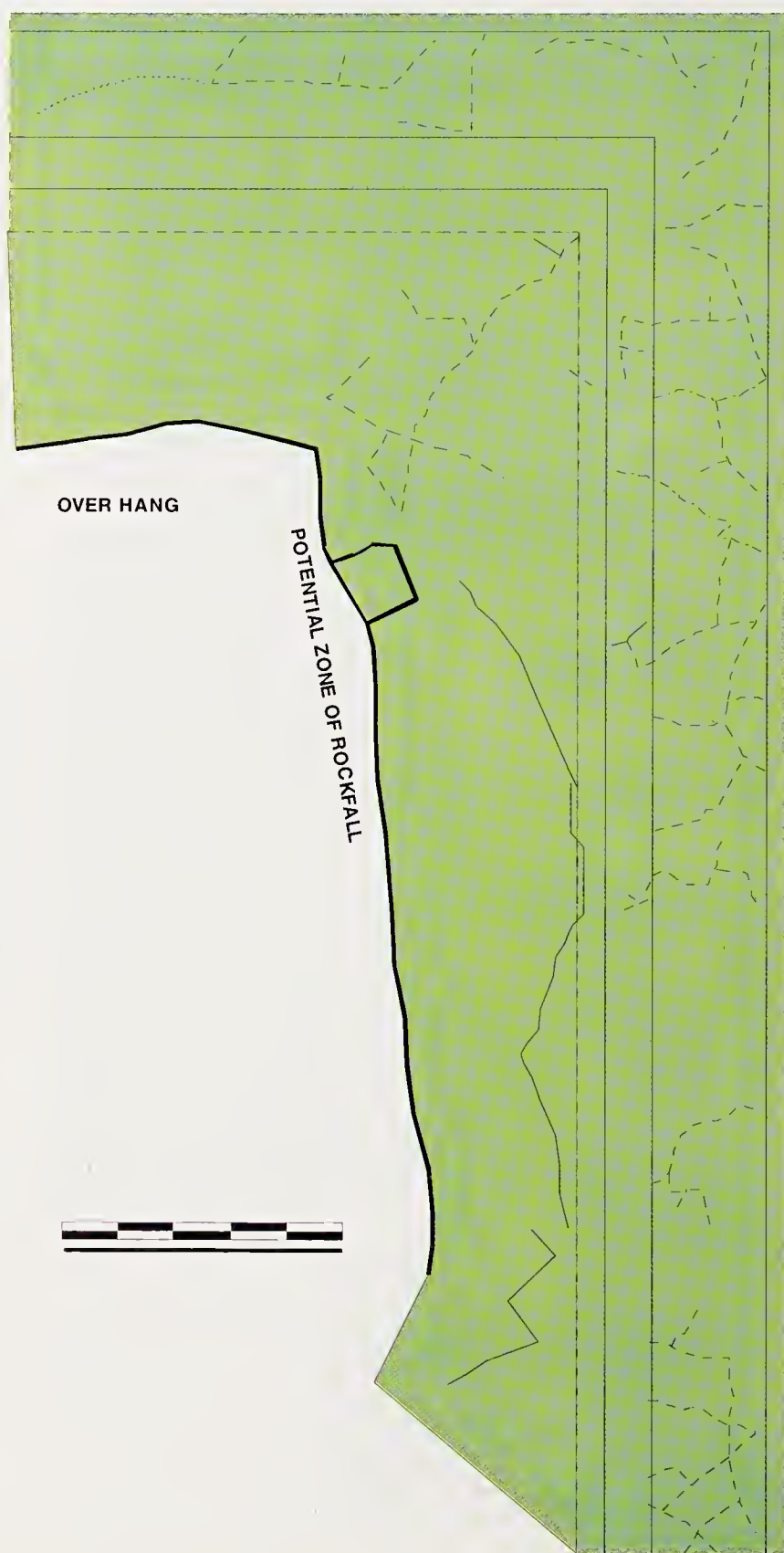
GEOLOGICAL LOG OF CROWN OF PART OF CAVE 16 AT ELLORA

SHEET - XI





GEOLOGICAL LOG OF CROWN OF PART OF CAVE 16 AT ELLORA
SHEET - XII

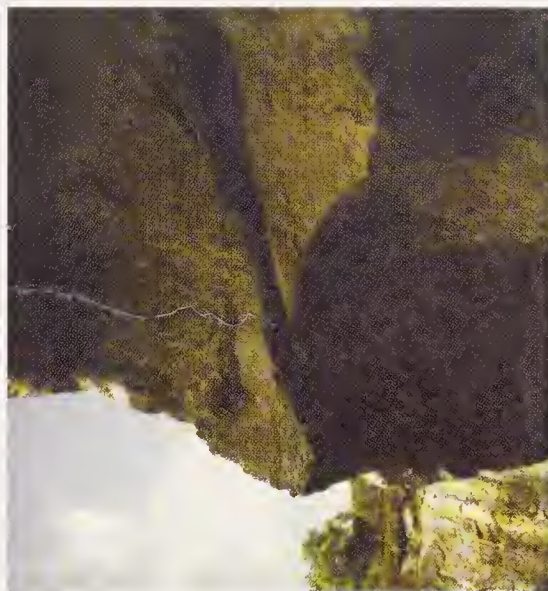




CAVE 16



WESTERLY DIPPING CRACK ABOVE CAVE 16



CRACK ON SOUTHERN FACE OF
CAVE 16 NEAR PAD LANKA



LAVA CHANNEL NEAR CAVE 16

Plate : VII-104





Plate : VII-106





is present at a height of 1 meter from ground level. The pillar (arch support) present in left side in courtyard is highly damaged because of development of horizontal open joints. Two joints present in the pillar at a height of 2m and 2.5m respectively, from ground level and have a spacing of 4-5 cm. The pillar on the right side in courtyard is already destroyed with remnant of basal portion only. Central hall consists of eight rectangular pillars with sculptures on it. Right and left walls have been carved for images of Ganesh and Parvati. A horizontal crack of category 3 is observed on left wall of cave, at a height of 2m from ground level. A unit contact is noted on inner column of hall, at a height of about 2m from ground level. Rock inside the hall is unweathered (Gr.I), however basal portion of all the pillars is slightly weathered (Gr.II). Sculptures present on left and right wall near entrance of shrine are damaged because of horizontal joints, and micro fractures. On the left and right side of roof of hall and right parikrama a crack infilling is observed. Few fractures of category II and III are noticed on the crown of the hall. In facade seepage is observed from horizontal cracks on left side (Plate VII – 110).

Treatment Include Grouting of pillar left side in verandah, encasing and repairing of pillar in left cell, Scrapping of rock surface and shortcrete up to retaining wall, and filling of two water tanks present above the cave. Existing drains is to be repaired and taken to bed rock and provided with weep holes on upstream side.

The geological log of the crown of cave 17 is presented in plate VII – 107 and section along the center line is presented in plate VII – 108.

CAVE - 18

This cave consists of a courtyard, a central hall and the shrine. Facade is in broken condition. There is one cell each on left and right sides of

courtyard. Four columns in front row and two columns in the back row support the hall. In central hall there are number of sculptures on walls and pillars. Left side, front wall and column indicate intrusion of quartz vein and a vug filling having a 2cm to 12cm wide gap along a joint plane trending N5°W/20°E at 1.70-m from ground level. Minor quartz veins are observed on the crown of central hall and continues up to antechamber. Two cracks of category III, present along crack in filling in left corner of crown of hall indicate water seepage along with a deposition of calcareous encrustation. In central hall rock is unweathered (Gr.I). A relief joint trending N27°W/40° S are present on left facade and a joint trending N-S/45°S is observed on the right facade on sloping ground. Seepage is noticed in these joint planes, and also from the facade and the base of the left cell in the courtyard (Plate VII – 110).

Suggested Treatment: Existing drain is to be repaired and taken to bed rock and provided with weep holes on upstream side.

The geological log of crown of cave 18 is presented in plate VII – 109.

CAVE - 19 A

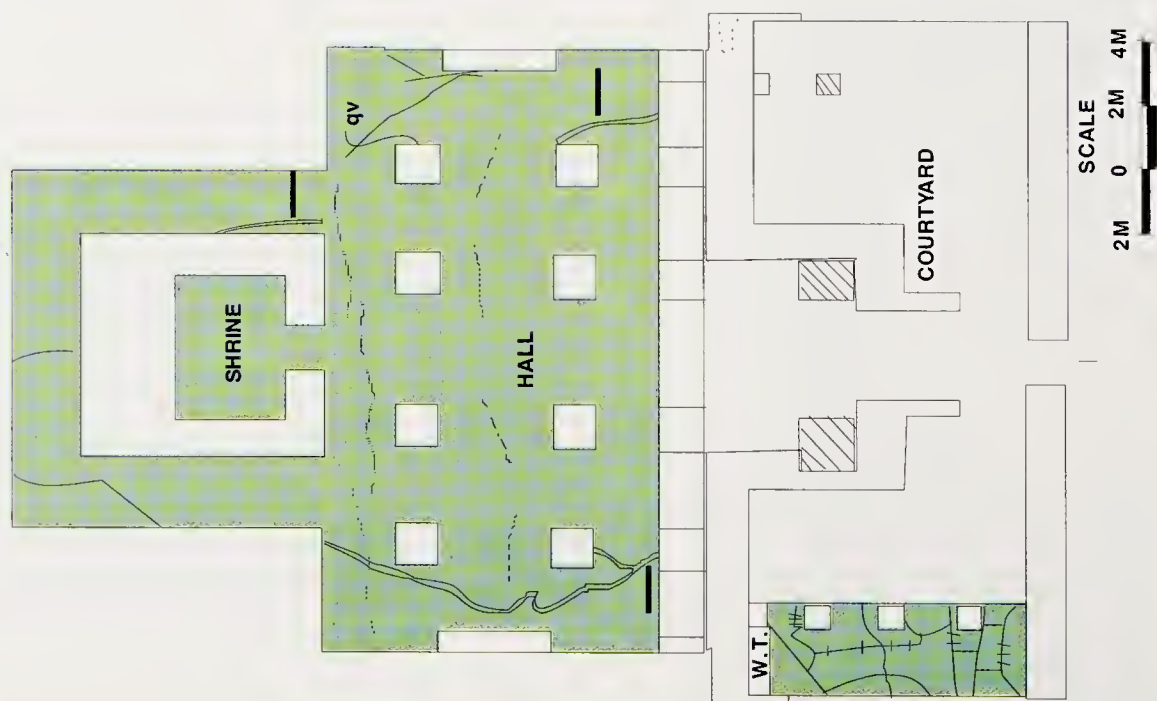
This cave represents Hindu faith. The front wall that supports the rock load has developed major fractures and the facade is in dilapidated condition. Rock mass present on left side of facade indicates a gently dipping crack along a weathered contact on a sloping ground. Number of quartz veins with vug filling is present on right side of entrance wall. Central hall is supported by a row of rectangle shaped columns in which the first row of column is completely destroyed and 1st column to the left has developed major fractures and is in a highly weathered (Gr.IV) condition. The 2nd column to the left side and first two columns on the right are



Plate : VII-107

GEOLOGICAL LOG OF CROWN OF CAVE 17A AT ELLORA

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- SLIGHTLY WEATHERED VESICULAR BASALT
- TRACE OF UNIT CONTACT / SQUEEZE UPS
- TRACE OF CRACKS / FRACTURES
- WATER SEEPAGE ZONES
- PLASTERED CRACKS
- EDGE OF BROKEN CROWN / ROCK FALL ZONES
- QUARTZ VEIN

HAZARD GRADATION OF CRACKS

- CATEGORY I STABLE, HAIRLINE
- CATEGORY II
- CATEGORY III
- CATEGORY IV
- CATEGORY V UNSTABLE OR AREAS WHERE TREATMENT IS REQUIRED

R. L. OF FLOOR: 621.43m
R. L. OF CROWN: 626.03m

M. M. POWAR
GEOLOGIST (SR.)

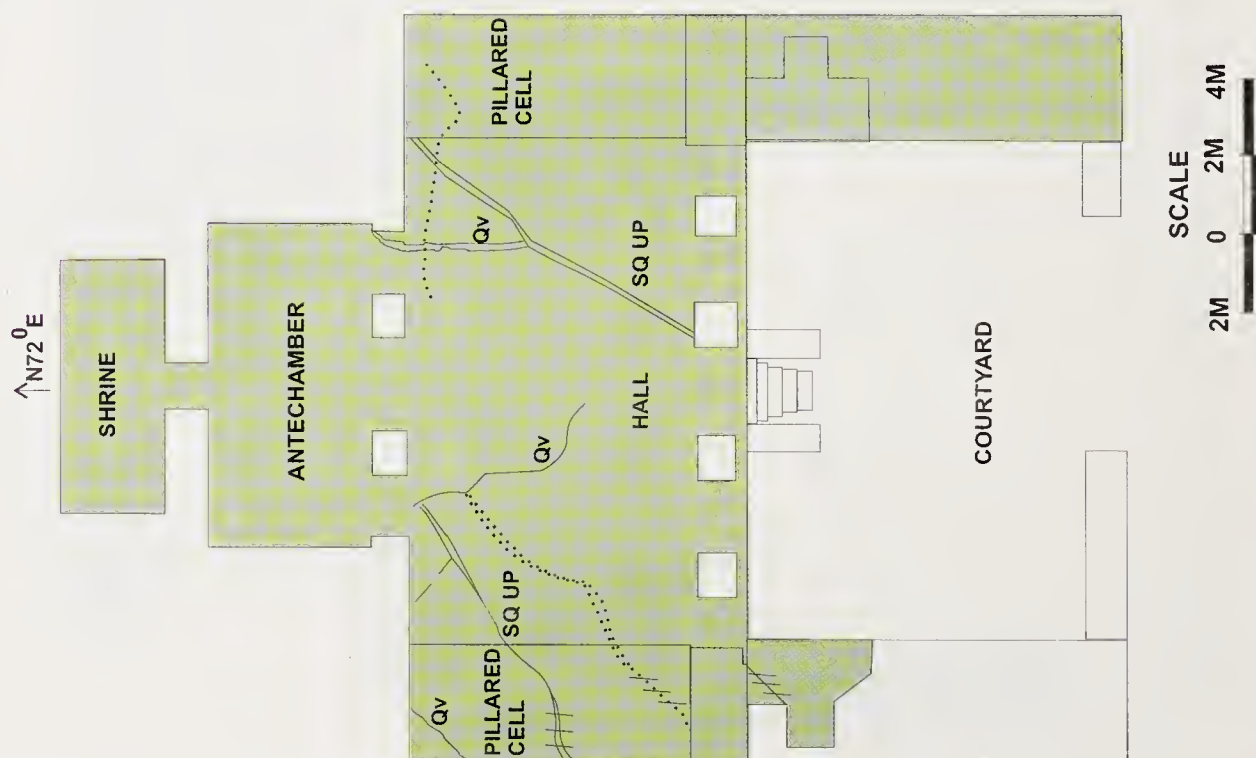
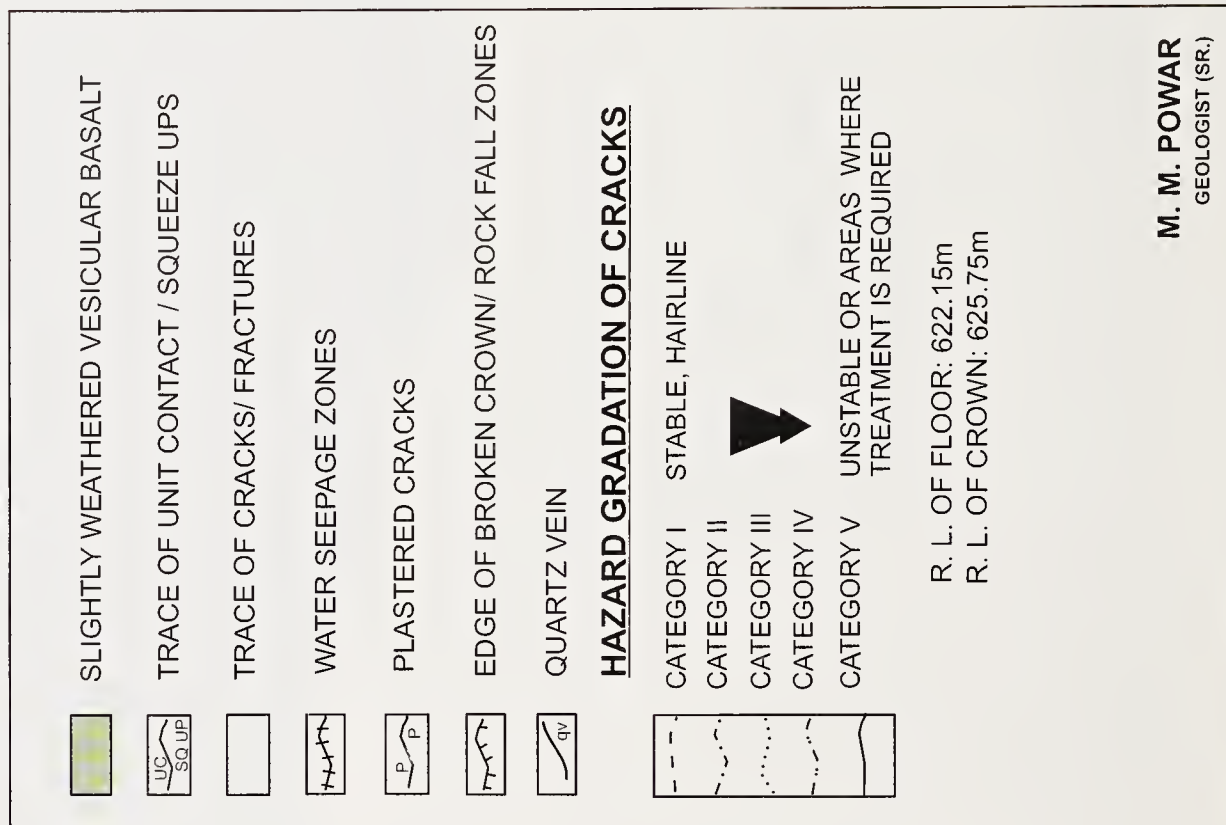
Plate : VII-108

GEOLOGICAL CROSS SECTION ALONG THE CENTRE LINE OF CAVE 17A AT ELLORA



GEOLOGICAL LOG OF CROWN OF CAVE 18 AT ELLORA

INDEX





Cave 17A Damaged Arch support and cracks in Facade.



Cave 17A Damaged left cell and seepage from Facade .



Cave 18, Seepage from relief crack and at base of left cell in verandah.



Cave 18, Intrusion of quartz vein & vug filling in a wall & pillar in verandah.



Cave 19A Damaged column and seepage from roof of verandah.



Cave 19 A Damaged columns and cemented pillars with iron bars.



half constructed cement concrete columns which are to be completed to sustain the rock load. Number of fracture planes / joint planes of category IV and V present on the crown of hall continue to the left and right walls and indicate heavy seepage with deposition of calcium carbonate. Seepage inside the cave is because of infiltration from the drainage channel situated on the left side near the entrance of the cave. A unit contact is observed on the crown of hall. Front portion of crown of hall is highly weathered (Gr.IV). Signature of rock fall is evident.

Suggested Treatment: Treatment includes encasing of pillars in verandah and completing construction to support roof, Scrapping of existing gunited surface and shotcrete upto 10 meter from portal of cave, and repairing of rest of existing gunited surface. Nala cut through crack in filled portion is to be lined upto 20 meter upstream.

The geological log of crown of cave 19 A is presented in plate VII – 111 and the section along the center line is presented in plate VII – 112.

CAVE - 20

This cave consists of a courtyard, verandah and a hall. There is no statue or sculpture inside the cave. The facade is projected out with unit contact indicating weak planes along which seepage is noticed. There is one cell each on left and right sides of courtyard. The facade portion is in a dilapidated condition with fracture zone where treatment is required. The right cell is incomplete. Unit contact is observed at a height of 2-2.5m above ground level. Seepage in the form of drops is observed from a vertical crack in the verandah. The only sculpture on front wall to the left of courtyard has lost its sharpness due to weathering and is damaged due to cracks. Basal

0.3mt. portion of cave is slightly weathered (Gr.II) as compared to rest of unweathered portion (Gr.I) of hall and verandah. Fracture / crack of category IV is observed on left wall at a height of 2m from ground level (Plate – 120).

Cave 20A is situated at a higher level than the adjacent cave 20 on its right and cave 21 on the left. The facade of cave is stable, however, a horizontal joint is observed along the unit contact of basaltic flow. The contact is highly vesicular, weathered (Gr.II), having a width of about 20 to 70 cm which are traced in to the cave. The verandah consists of four rectangle pillars supporting the rock cover and are carved with designs. Right side cornered pillar is repaired with cement. There is a pillared porch each on the left and right aisle. Development of cracks is noticed in the upper right corner and on the right side of front shrine wall. A joint / fracture of category III is observed on the right pillared porch consisting of 2 to 5 cm thick quartz vein along a weathered basaltic flow contact indicating development of calcium encrustation accompanied by seepage. Thin quartz veins are also observed.

Suggested Treatment: Shotcrete upto existing drain (upto 10 meter.) and improvement of drainage are the treatment measures suggested

The geological log of crown of cave 20 is presented in plate VII – 113.

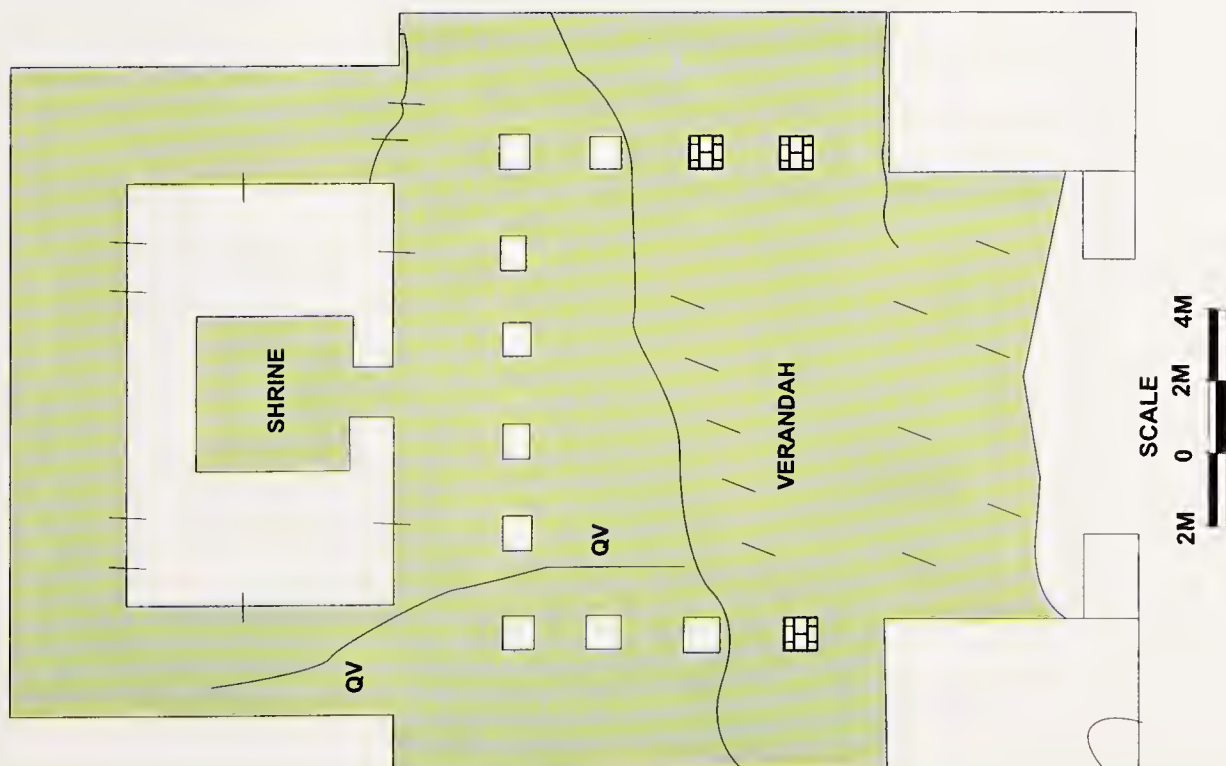
CAVE – 21

This cave is adjacent to 20A, and is known as Ramashwara cave temple. It has many well preserved beautiful sculptures. It consists of a courtyard, a hall, and the shrine. Courtyard contains a pillared porch each on the left and right sides. The right porch is with two pillars only

GEOLOGICAL LOG OF CROWN OF CAVE 19 A AT ELLORA

Plate : VII-111

N60°E



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	QUARTZ VEIN
HAZARD GRADATION OF CRACKS	
	CATEGORY I STABLE, HAIRLINE
	CATEGORY II
	CATEGORY III
	CATEGORY IV
	CATEGORY V UNSTABLE OR AREAS WHERE TREATMENT IS REQUIRED
R. L. OF FLOOR: 616.07m R. L. OF CROWN: 619.67m	
M. M. POWAR GEOLOGIST (SR.)	





Plate : VII-112

GEOLOGICAL CROSS SECTION ALONG THE CENTRE LINE OF CAVE 19A AT ELLORA

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UNIT CONTACT

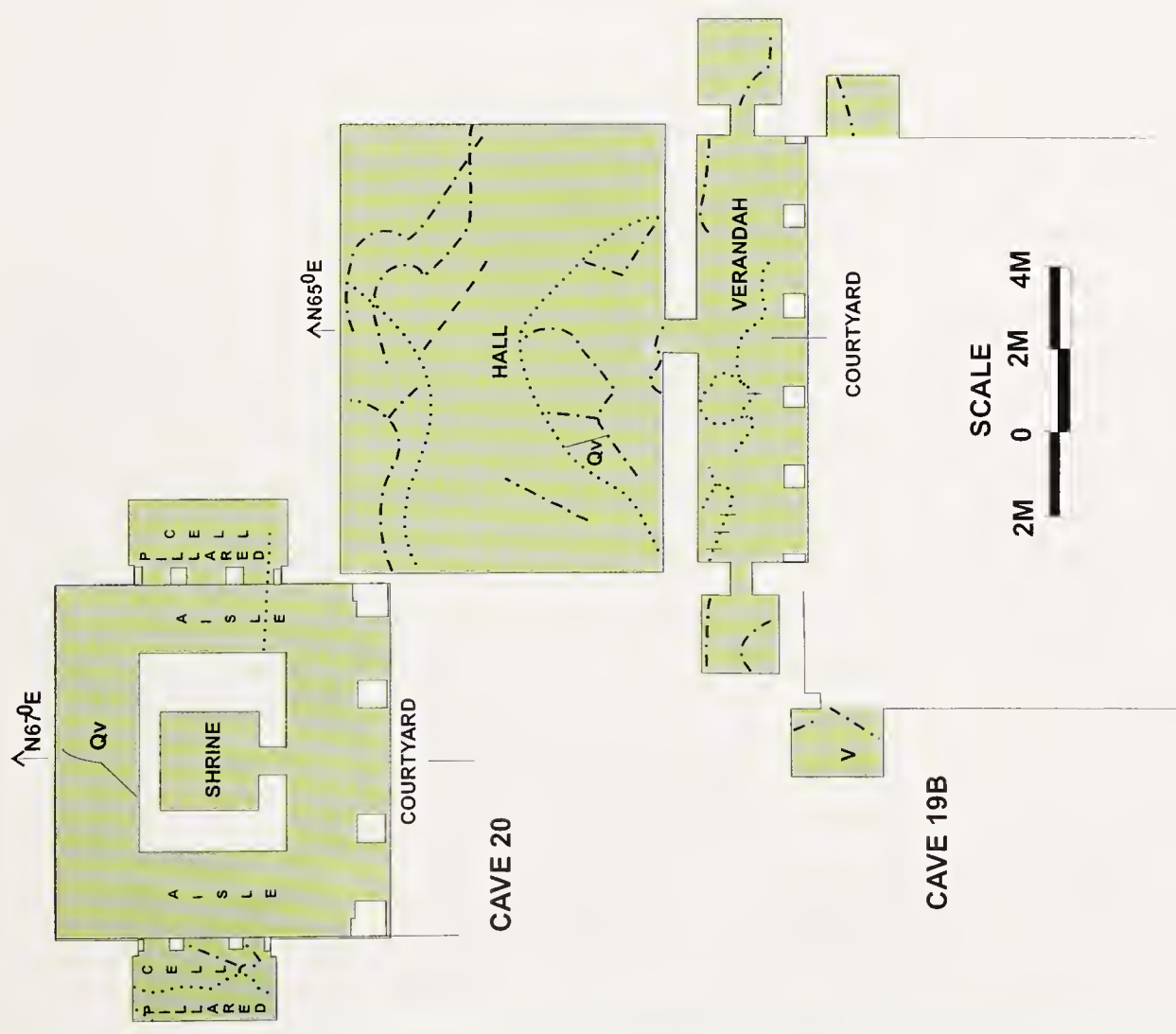


FLOW I



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	SLIGHTLY WEATHERED VESICULAR BASALT
	TRACE OF UNIT CONTACT / SQUEEZE UPS
	TRACE OF CRACKS/ FRACTURES
	WATER SEEPAGE ZONES
	PLASTERED CRACKS
	EDGE OF BROKEN CROWN/ ROCK FALL ZONES
	QUARTZ VEIN
HAZARD GRADATION OF CRACKS	
	CATEGORY I STABLE, HAIRLINE
	CATEGORY II
	CATEGORY III
	CATEGORY IV
	CATEGORY V UNSTABLE OR AREAS WHERE TREATMENT IS REQUIRED
R. L. OF FLOOR: 618.28m R. L. OF CROWN: 621.28m	
M. M. POWAR GEOLOGIST (SR.)	





without a roof. The facade / roof of cave is supported by six ornamented pillars. There is a unit contact at a height of 2 meter above the floor level. Central hall is of rectangular shape with one pillared cell each on left and right sides. Number of fractures of category II and III are present on the crown of central hall. Encrustation of calcium carbonate is observed in the corners of hall. A unit contact with pipe amygdales is observed at the base of left cell. A horizontal crack / fracture with a spacing of 1 to 2 mm of category III is observed at a height of 3.90m from the floor level on the left front wall of central hall. Another fracture of category III is observed cutting across the shrine upto the left and right walls of the shrine and is traced into the parikrama. The rock mass of chabutra (Nandi portion) is slightly weathered (Gr.II) and the sculptures have lost their sharpness and partly damaged because of weathering. Seepage in the form of continuous dripping is noticed from crown portion on the right pillared porch in the central hall (Plate – 120).

Suggested Treatment: (a) Shotcrete upto existing drain, (b) Relaying of existing drain cutting upto bedrock and providing weep hole for collecting water in soil surface. (c) Wide gap in left wall in verandah to be filled or shotcreted.

The geological log of crown of cave 21 and the section along the center line is presented in plate VII – 114 & VII – 115 respectively.

CAVE - 22

The entrance of the cave is through walled structure and is in a dilapidated condition. The rock is slightly weathered (Gr.II) and has many horizontal fractures. Cave consists of a courtyard, a central hall, an antechamber and the shrine. There is a cell each on left and right sides in

courtyard. The right cell in courtyard contains two fractures of category II on the crown / roof. The left cell is a small, uneven, excavated portion, which shows category II fracture. A unit contact with a crack- in- filling is seen on the crown of the cell. Central hall contains a minor quartz vein along a fracture. Few category II and III fractures are observed on the left and right pillared porch of the central hall. The left aisle of the central hall shows fractures of category III with seepage on the front wall side. Seepage is also noticed on the right cell of the central hall along a vertical crack in the crown portion and from a horizontal joint above the left cell in the courtyard. Surfaces above the left cell need to be treated. The sculptures near the crown portion in the central hall and in the antechamber have lost their sharpness and are partly damaged due to micro fractures. Rock mass of central hall, shrine and the chabutra are slightly weathered (Gr.II.)

Suggested Treatment: (a) Shotcreting in northern part upto rock cut escarpment face (approx. 8m) and at base of escarpment, (b) providing drainage and joining it to existing drainage.

The geological log of crown of cave 22 is presented in plate VII – 116.

CAVE - 23

Cave 23 is situated at a higher level than the cave 24 and consists of open courtyard, five rectangular pillars in verandah and one pillar in courtyard. There are three cells on left side of the courtyard. One of the cells contains Shivling and another a sculpture of Trimurthy. There is an incomplete portion with five cells (shrine) in a series with varying depths in verandah and one cell each on left and right. Fracture of category IV trending N15°W-S15°E (Grde II) is observed on the crown

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-  EDGE OF BROKEN CROWN / ROCK FALL ZONES
-  QUARTZ VEIN

HAZARD GRADATION OF CRACKS

- | | | |
|---|--------------|---|
|  | CATEGORY I | STABLE, HAIRLINE |
|  | CATEGORY II | |
|  | CATEGORY III | |
|  | CATEGORY IV | |
|  | CATEGORY V | UNSTABLE OR AREAS WHERE TREATMENT IS REQUIRED |

R. L. OF FLOOR: 622.23m
R. L. OF CROWN: 627.03m

M. M. POWAR
GEOLOGIST (SR.)

Plate : VII-115

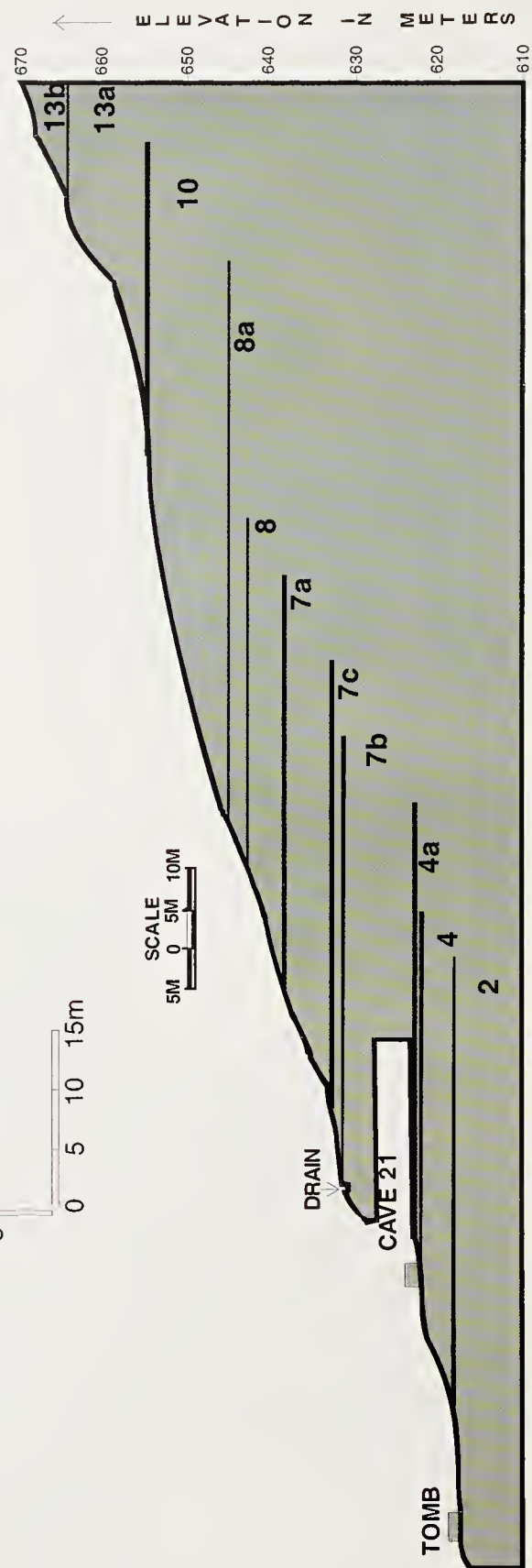
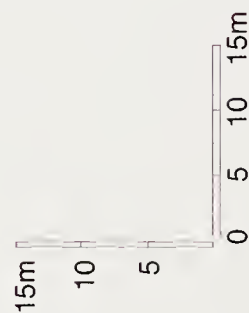
GEOLOGICAL CROSS SECTION ALONG THE CENTRE LINE OF CAVE 21 AT ELLORA

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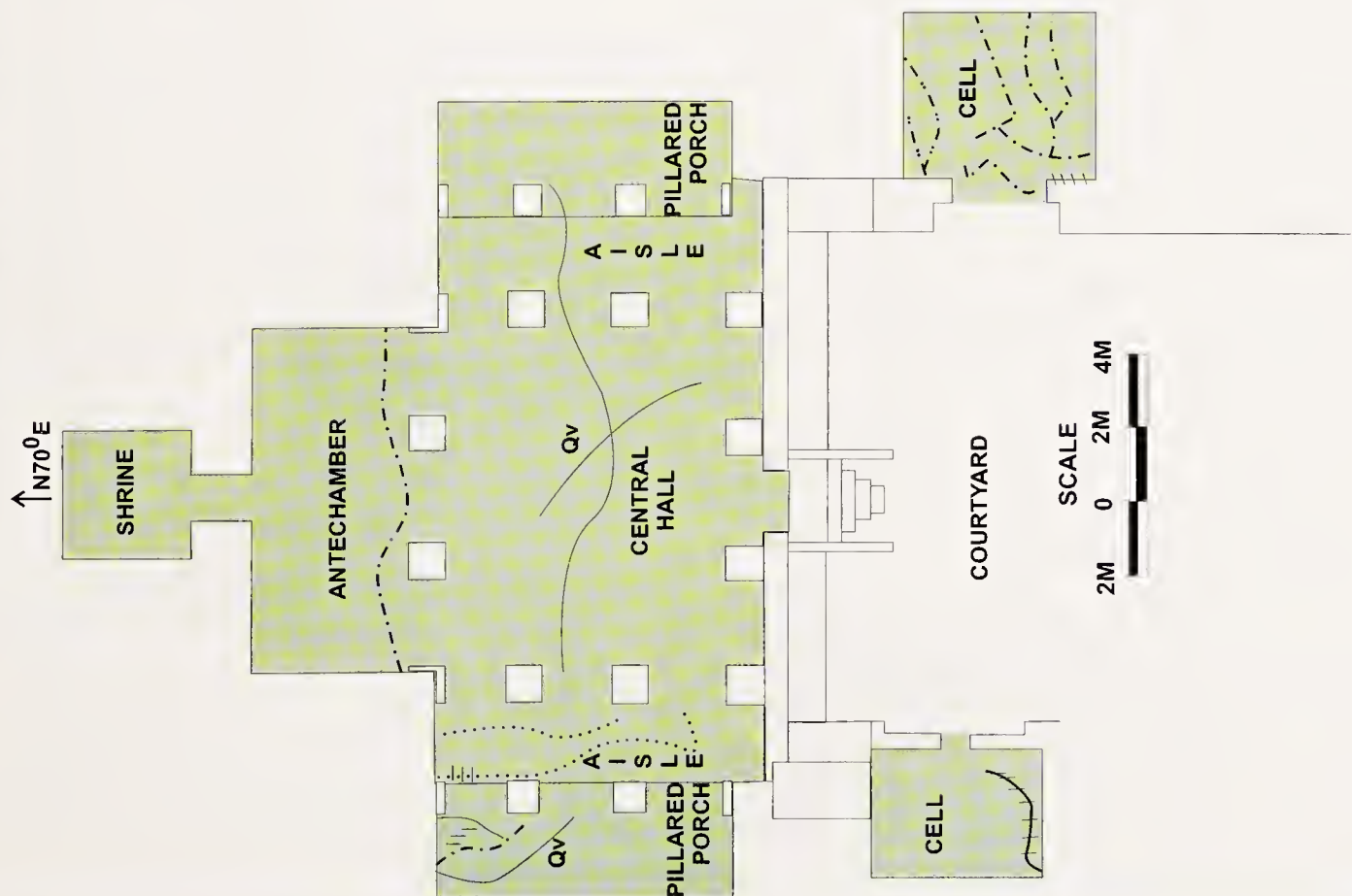
UNIT CONTACT



FLOW I



GEOLOGICAL LOG OF CROWN OF CAVE 22 AT ELLORA





of verandah following a unit contact, where heavy seepage with continuous dripping and deposition of calcium carbonate in the form of stalactite measuring from 1mm to 2cm in lengths is observed. Rock is highly weathered (Grade IV) along this crack. A quartz vein trending N85°E - S85° W having a varying width of 1 to 3cm is observed on the roof/crown of verandah. Rock mass above the left side cell in courtyard has developed an open joint along the slopping ground. The rock of this cell is slightly weathered (Grade II).

CAVE - 23A is a very small cave excavated at lower level than cave 22 and consists of a courtyard, central hall and the shrine. Shrine contains sculpture of Shivling. The rock is blackish gray, slightly weathered (Gr II) vesicular basalt. The vesicles are filled with green earth. Facade indicates a unit contact along with a highly weathered portion (Gr IV) of 20 – 40 cm thickness at about 2.55 m above the ground level. This portion is moist with water seepage. Category II fracture is observed in Central hall and shrine. A quartz vug is observed on the walls of shrine.

Suggested Treatment: (a) Shotcreting upto existing drain on top, (b) Removal of stray boulders and removal of plants.

The geological log of crown of cave 23 and 23A is presented in plate VII - 117.

CAVE - 24, 24A & 24B

Cave 24 consists of a courtyard and four cells in a row. There is a cell with a hall, on the right. The cells which are in rows, indicate a stable roof without any fractures where as the cell on the extreme left is in a dilapidated condition, the two pillars of which need immediate treatment. The

unit contact is observed on the front wall at a height of 1.20 m from ground level. A fracture of category III is observed on the right side wall of this cell. The crown of right side cell indicates minor quartz vein and fractures of category II. Rest of the cells seems to be stable. Wall between 1st & 2nd right shrine is having a large hole. Seepage in the form of drips is noticed from the left corner of the shrine cell (Plate VII-120). Rock mass of this cell is moderately weathered (Grade III) compared to rest of slightly weathered rock mass (Grade II).

These two caves are joined with each other with a common wall and are at a higher level towards left of cave 23. Cave 24B is at right to that of cave 24A, and consists of verandah and shrine. The crown of verandah contains fracture / valley relief joint of category V trending N10°E/22°NW and continues up to the wall where seepage is noticed. This fracture needs immediate treatment. Cave 24B consists of verandah supported by two rectangular pillars and shrine. In the crown of verandah towards left side a fracture category II is observed. Facade above the right cell is highly fractured and moderately weathered (Grade III) due to water action. Seepage is noticed in the form of continuous dripping from right unfinished cell. Sculptures of Ganesh present on front wall of verandah has lost its sharpness and is slightly weathered (Grade II) due to water action. Rock is slightly weathered in cave 24A on left side wall of courtyard where as rock in rest of cave is slightly weathered (Grade II) (plate VII- 120).

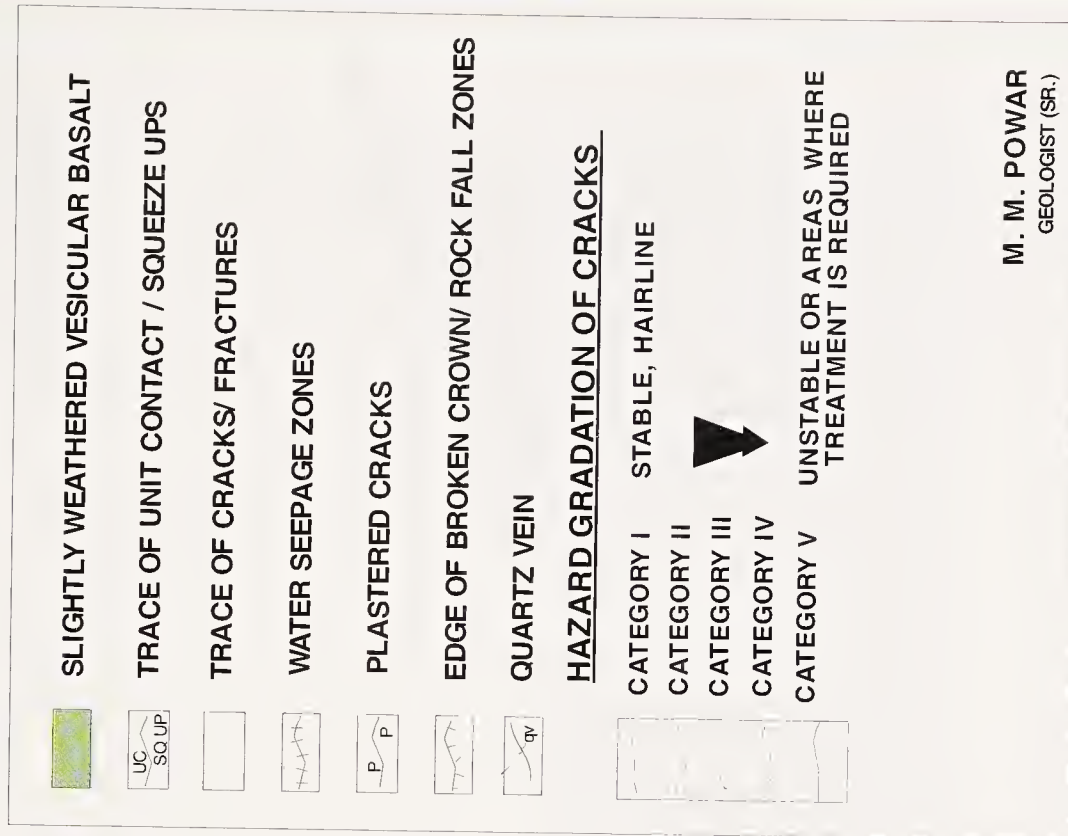
Suggested Treatment: Treatment proposed is extending shotcrete upto 3 meter from facade of cave 24A.

The geological log of crown of cave 24, 24A and 24B is presented in plate VII – 118 and the section along the center line is presented in plate VII – 119.

Plate : VII-117

GEOLOGICAL LOG OF CROWN OF CAVE 23 & 23A AT ELLORA

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M. M. POWAR
GEOLOGIST (SR.)

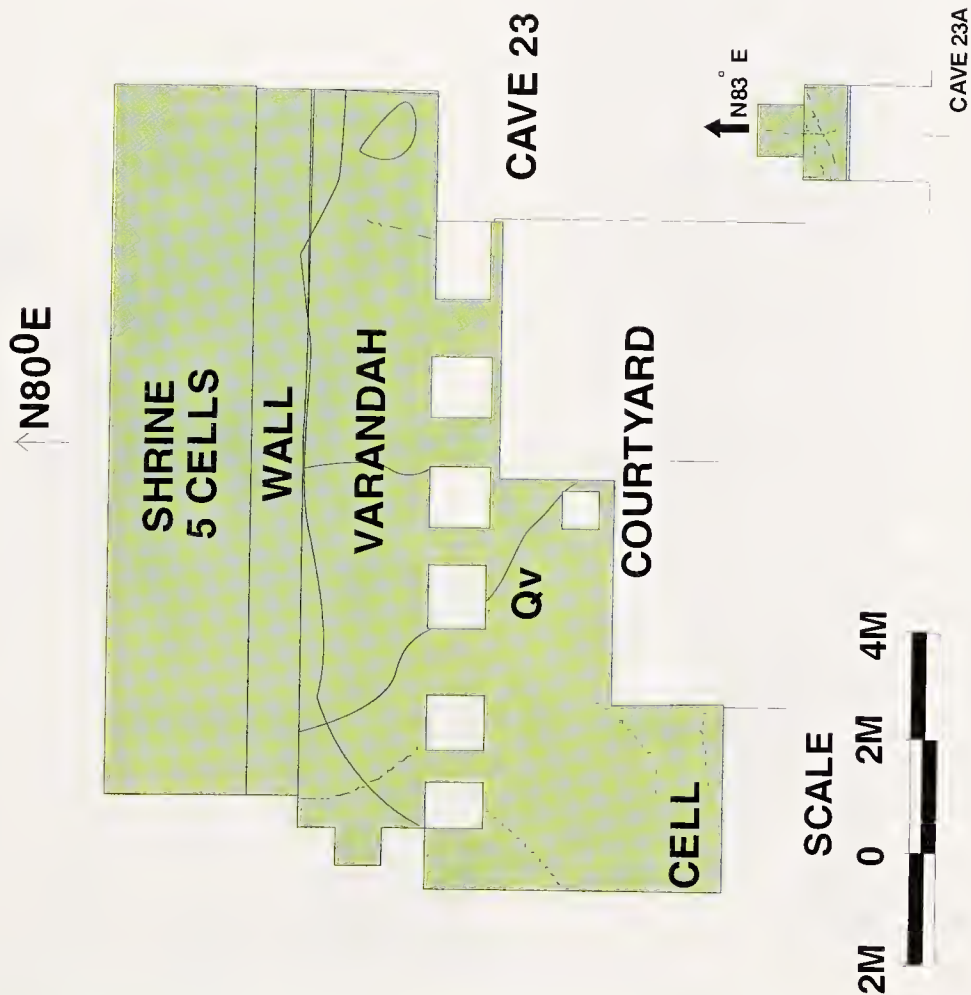
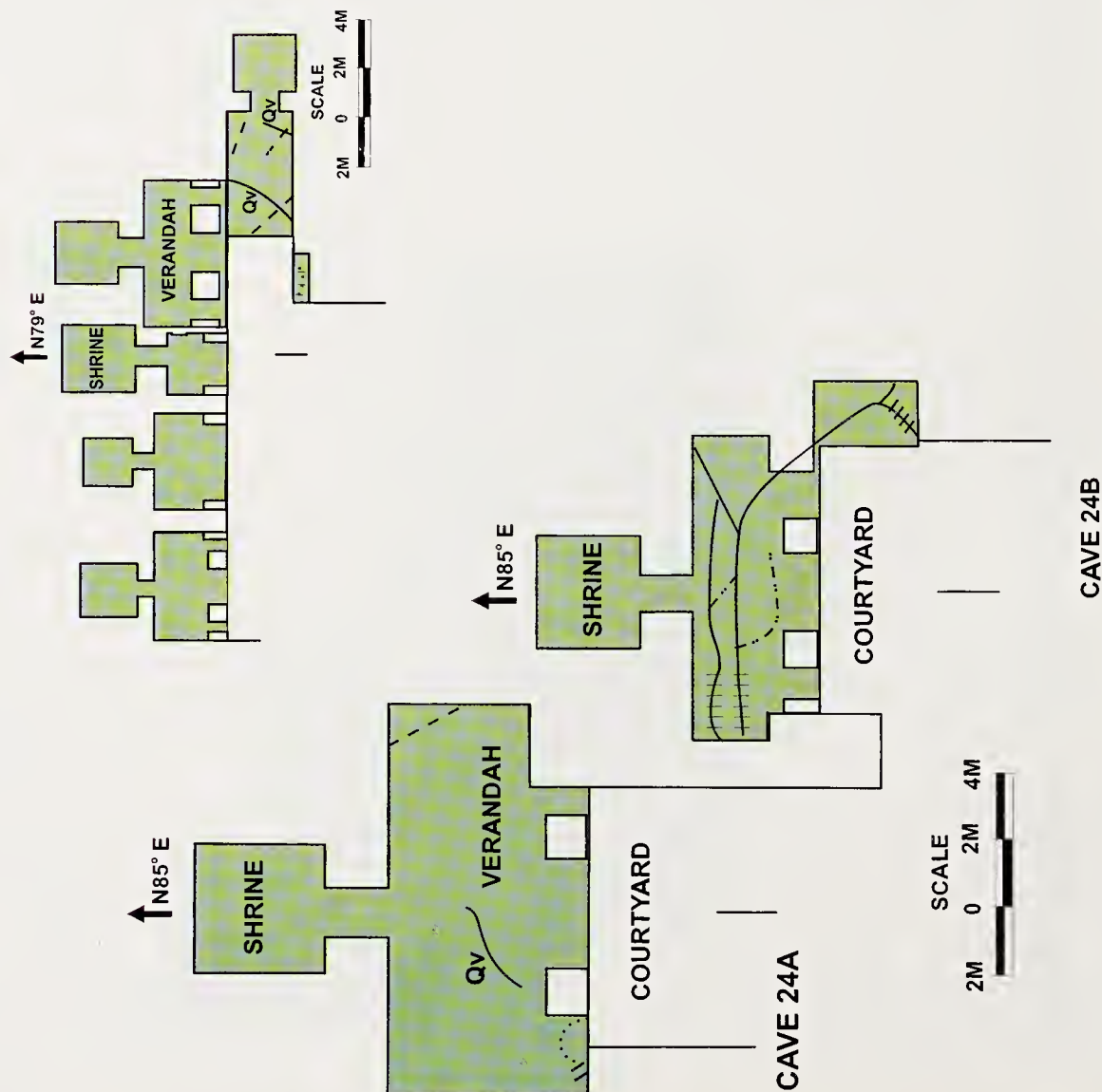




Plate : VII-118

GEOLOGICAL LOG OF CROWN OF CAVE 24, 24A AND 24B AT ELLORA



M. M. POWAR
GEOLOGIST (SR.)

Plate : VII-119

GEOLOGICAL CROSS SECTION ALONG THE CENTRE LINE OF CAVE 24 AT ELLORA

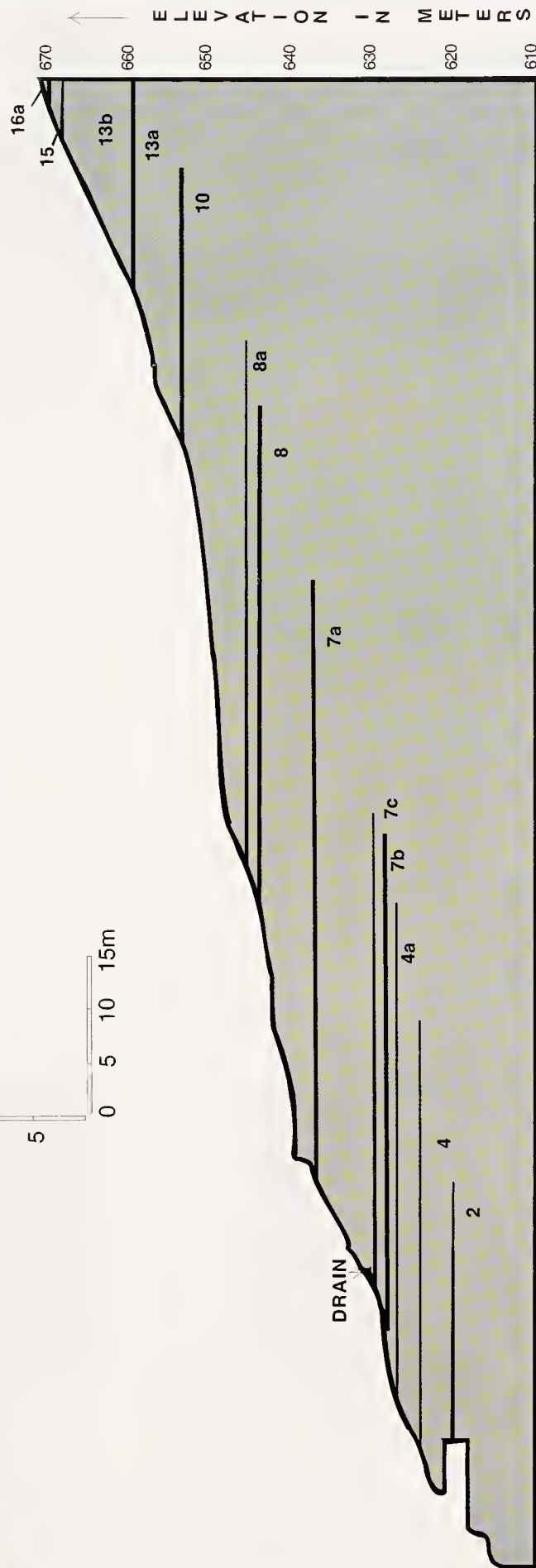
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UNIT CONTACT



FLOW I





Cave 19B Seepage through unit contact in a Facade.



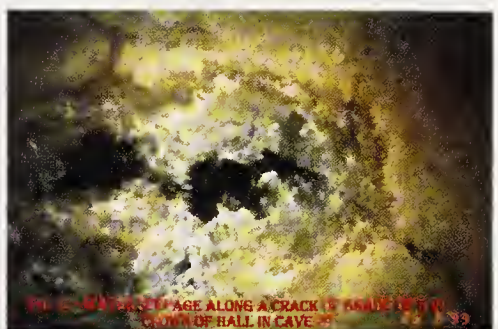
Cave 21, Weathering along a unit contact near the floor of verandah.



Cave 23, Damaged pillars of extreme left cell.



Cave 24, Seepage through relief joint in a roof of verandah.



Cave 29 Seepage from fracture of grade 5 in roof of verandah.



Cave 30 Damaged entrance with seepage from joints in roof.



CAVE - 25

This cave is wide and open consisting of courtyard, verandah, left and right aisle, antechamber and shrine. The crown portion near entrance of shrine bears an image of Surya seated in his chariot driven by seven horses. The 6 pillars in the courtyard are now destroyed and only a remnant base is present. The overhang portion in courtyard is unsupported and has developed many cracks of category II. Number of fine quartz veins are present in the crown portion of courtyard. The verandah is supported by a row of pillars. A category III fracture trending N10°E-S10°W is observed on the crown of verandah. Vug filled with cherty quartz is observed on the front side of right wall of shrine. A unit contact is observed at about 50 to 60 cm above the ground level at the base of cell in the right side of verandah. The floor of the verandah and antechamber is cemented. Outside the cave towards right there is a water tank having a depth of 3.30m and 11.40 x 5.40m length and breadth, which should be covered / filled with concrete to prevent any accident. Seepage is mainly from facade in form of continuous droplets and also from N10°E - S10°W trending category III crack in the crown of verandah. A highly fractured and jointed portion is noticed in the left and right side of facade where rock mass may fall in near future. Inner columns, verandah and shrine portion is unweathered(Gr.I). A sculpture present in right hand corner in verandah has lost its sharpness and has been damaged due to joints and micro fractures. Nandi in courtyard is destroyed and only basal portion is present.

Suggested Treatment: (a) Existing pillars to be repaired, (b) Shotcreting upto 5 meter from cave portal.

The geological log of crown of cave 25 and the

section along the center line is presented in plate VII – 121 & VII – 122 respectively.

CAVE - 26

This cave is similar to that of cave 21 and identified as 'Rashtrakuta cave temple'. This cave consists of a central hall, supported by rectangular ornamented pillars and a shrine. The facade is high with stable rock cover where only minor fractures are observed. There is a unit contact at much higher level above the cave and is marked by a zone of approximately 1-meter of moderately weathered(Gr.III) grayish black fine-grained basalt. Along this zone seepage is noticed. There is one cell each on left and right side of central hall and are at higher level than the floor of the hall. A unit contact is observed on front wall, right side of central hall and can be traced throughout the cave and is marked by highly vesicular, weathered basaltic(Gr.II) band of 50 cm thickness. Highly fractured, jointed zone observed on right side facade of cave above the water tank may lead to rock fall in future. Rock inside the cave is unweathered(Gr.I) and sculptures present on walls and central hall near shrine entrance has been damaged due to jointed nature of rock. Number of quartz veins and vugs filled with zeolites and fractures of category II & III are observed on the crown of Central hall, left and right cell in parikrama. Pinching and swelling nature of quartz vein with lenticular vug of size 2.70m lengths and 12cm width is present at a height of 3m from ground level on the right side wall of right parikrama. Right side front wall of central hall indicates plastering of wall, which has peeled off from most places.

Suggested Treatment: (a) Filling of cracks inside the cave. (b) Shotcreting upto 5 meter upstream. (c) Epoxy grouting.

The geological log of crown of cave 26 is presented in plate VII – 123.

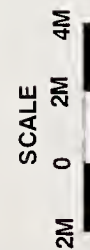
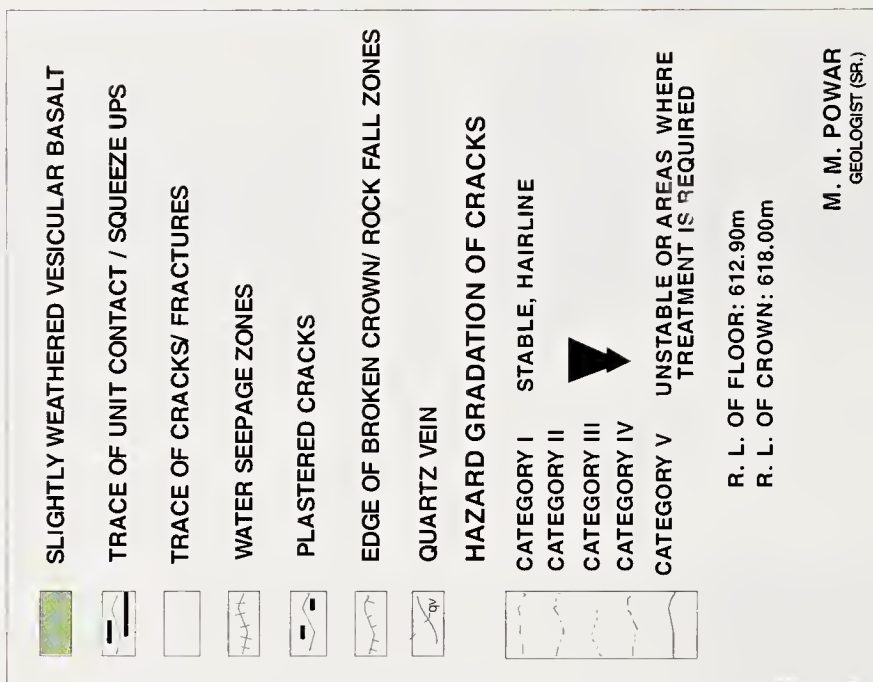
Plate : VII-121

GEOLOGICAL LOG OF CROWN OF CAVE 25 AT ELLORA

↑ N72° E



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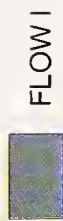


GEOLOGICAL CROSS SECTION ALONG THE CENTRE LINE OF CAVE 25 AT ELLORA

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UNIT CONTACT



FLOW I

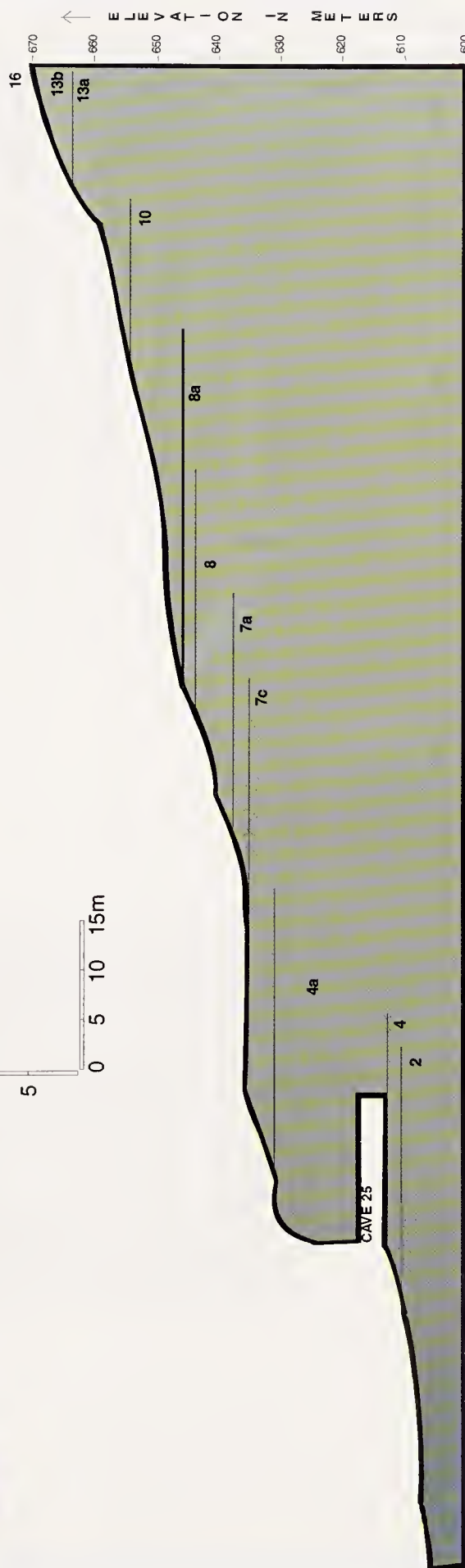
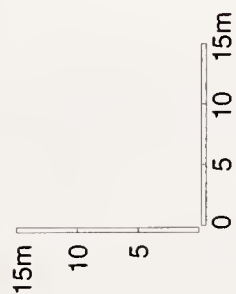




Plate : VII-123

GEOLOGICAL LOG OF CROWN OF CAVE 26 AT ELLORA

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	SLIGHTLY WEATHERED VESICULAR BASALT
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	EDGE OF BROKEN CROWN/ ROCK FALL ZONES
	QUARTZ VEIN
HAZARD GRADATION OF CRACKS	
	CATEGORY I STABLE, HAIRLINE
	CATEGORY II
	CATEGORY III
	CATEGORY IV
	CATEGORY V UNSTABLE OR AREAS WHERE TREATMENT IS REQUIRED

R. L. OF FLOOR: 607.53m
R. L. OF CROWN: 612.58m

M. M. POWAR
GEOLOGIST (SR.)





CAVE - 27

This cave is known as 'Gopilena'. It has triple shrines on the rear wall and side walls of its mandap. This cave consists of 4 octagonal columns supporting the facade and connected to central hall and shrine. The facade of the cave is stable except towards right side where small jointed, and fractured portion is to be removed and or treated. A small rectangular underground water tank of 2.20m x 1.20m is present outside on the right hand corner of the courtyard. A weathered unit contact (Gr.II) with pipe amygdales can be seen in the right hand side of courtyard at a height of 2.5 m from ground level. Central hall consists of open rectangular space with one cell each on left and right side. Left side cell is at higher level (80 cm) than the right one. Another small cell is present in the right side of front wall of central hall. The crown portion of central hall in front of left cell shows weathered unit (Gr.III) contact with fracture of category III where seepage is noticed. The crown of central hall indicates number of fractures / cooling cracks of category II mostly trending N10°W – S10°E direction. Water seepage is noticed from facade of cave in form of droplets. Rock inside the cave is slightly weathered (Gr.II) and sculptures present on walls of central hall are damaged due to joints and microstructures.

Suggested Treatment: Epoxy / polymer coating for weathered rock.

The geological log of crown of cave 27 and the section along the center line is presented in plate VII – 124 & VII – 125 respectively.

CAVE - 28

This cave is excavated approximately in middle of 37m section exposing number of horizontal

bedded units of varying thickness. A nala draining on top of hill forms a waterfall just in front of the cave and is known as 'Velganga'. A small foot track follows upto cave 28 and continues with a flight of stairs upto cave 29. Cave 28 is a incomplete cave and consists of courtyard and shrine. Shrine at present does not have any sculpture or carvings. The cave is excavated in moderately to highly weathered (Gr.III/IV) vesicular basalt. At the base of cave the vesicles are prominent and a unit contact can be seen on the walls of cave. Diameter of vesicles measures upto 3 mm. Horizontal joints along unit contacts are open and require treatment. The floor of cave is uneven rocky surface.

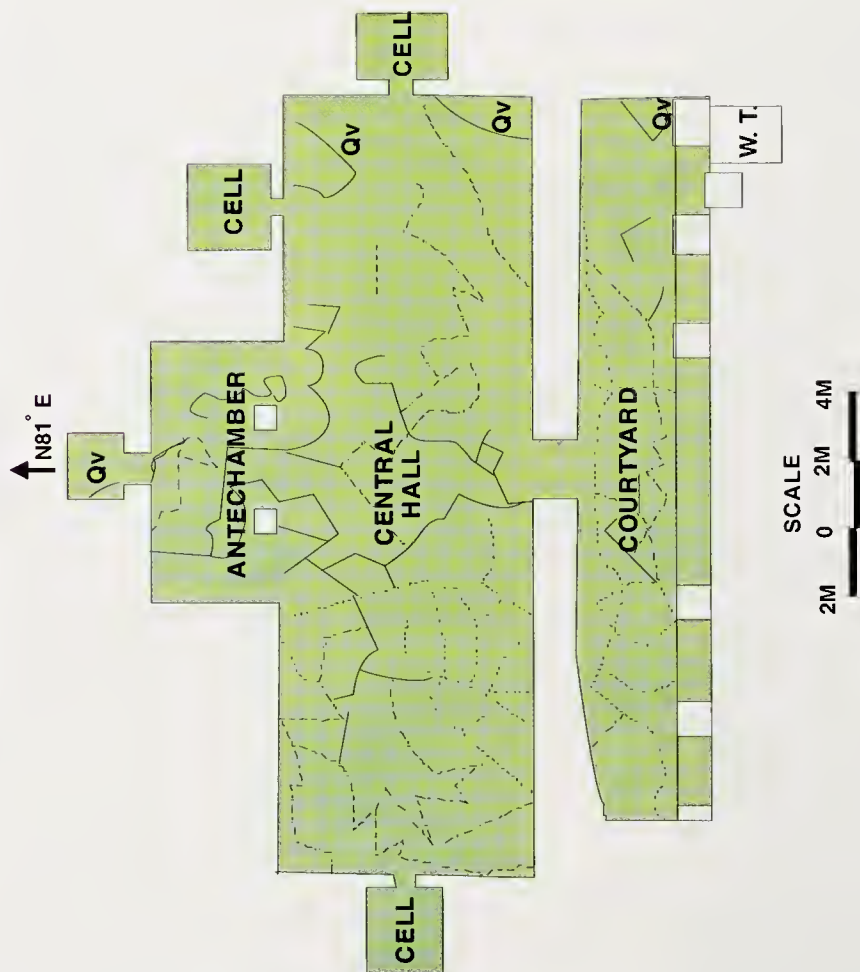
Suggested Treatment: Epoxy / polymer coating for weathered rock.

CAVE - 29

This cave is the last cave carved in the series of Hindu caves and it has a sculpture of Shivling in shrine. This cave is known as 'Dhumarlena' or 'Sita Ki Nahani'. It consists of courtyard, central hall, and shrine. In the right side of courtyard two pillared cells are present. The 2nd cell is incomplete. To the left of courtyard there is only one small cell. Four cells are present on the left hand side, outside of courtyard where the rock mass on the slopping ground in overburden has developed open joints which has to be removed or slope stability measures are to be undertaken to prevent any damage to the cells. Central hall consists of two rows of rectangular pillars and three aisles each on left and right side. Fracture of category V is present above the entrance in facade trending N20°E to N75°E /90° direction and continues upto central hall. Distress cracks are observed in some pillars. Calcareous encrustations due to seepage are present along this fracture plane.

Plate : VII-124

GEOLOGICAL LOG OF CROWN OF CAVE 27 AT ELLORA

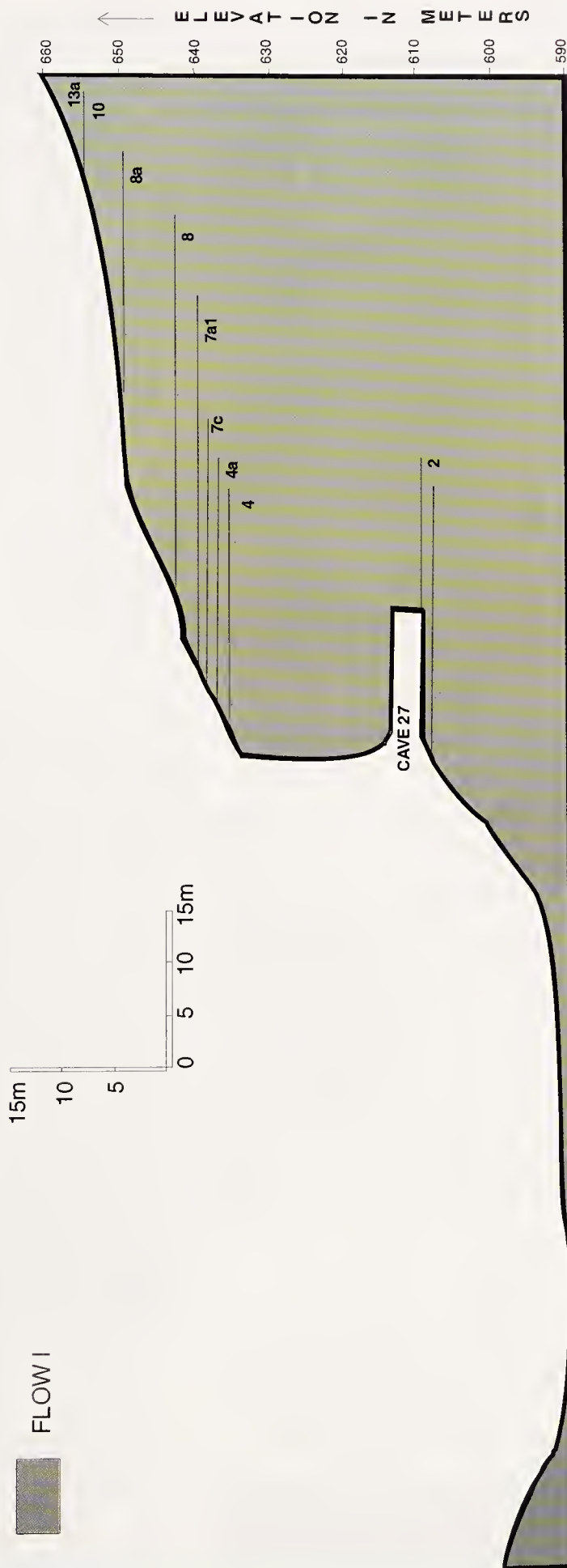


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	TRACE OF UNIT CONTACT / SQUEEZE UPS
	TRACE OF CRACKS/ FRACTURES
	WATER SEEPAGE ZONES
	PLASTERED CRACKS
	EDGE OF BROKEN CROWN/ ROCK FALL ZONES
	QUARTZ VEIN
HAZARD GRADATION OF CRACKS	
	CATEGORY I STABLE, HAIRLINE
	CATEGORY II
	CATEGORY III
	CATEGORY IV
	CATEGORY V UNSTABLE OR AREAS WHERE TREATMENT IS REQUIRED
R. L. OF FLOOR: 609.87m R. L. OF CROWN: 613.57m	
M. M. POWAR GEOLOGIST (SR.)	

GEOLOGICAL CROSS SECTION ALONG THE CENTRE LINE OF CAVE 27 AT ELLORA

INDEX





Fracture of category III trending $N20^{\circ}W - S20^{\circ}E/90^{\circ}$ is present on the roof of 3rd left aisle where as another fracture of category 3 trending $N25^{\circ}W-S25^{\circ}E/90^{\circ}$ is also observed on the roof of 2nd right aisle and continues towards Central hall. A few veins of quartz are observed on the roof of 2nd right aisle trending $N15^{\circ}W$ to $N25^{\circ}W/90^{\circ}$ and continue upto shrine. Quartz vein trending $N60^{\circ}W-S60^{\circ}E/90^{\circ}$ having a width of 2-4 cm is present on the roof of 2nd left aisle in the back side. Joint developed due to quartz vein along lenticular vugs is present on the wall of 2nd right aisle and is being repaired using cement.

On the left side of left aisle, stairs in open passage lead to a cell in front side and a small way to the pillared porch adjacent to it. This cell and pillared porch do not have any sculptures and are in unfinished condition. Dripping of water is noticed in the facade open passage of cave. Locally water logging conditions are observed in a narrow open portion in front of pillared porch. In the porch there are six pillars in a row and are in highly damaged condition. The right 1st and 4th pillars are moderately weathered (Gr.III) and are narrow at the base. 2nd pillar is reconstructed masonry pillar and last i.e. 6th pillar is in cement concrete. 3rd & 5th pillars have perished and only top overhang portion is seen. Crown of the cell and pillared porch contain number of category IV and V cracks. Rock fall of rolled boulders is noticed in the open narrow passage.

Suggested Treatment: (a) Treatment for distressed pillars in central hall. (b) Repairing and filling of cracks in left cell. (c) Shotcreting 5 meter upto retaining wall and improving drainage.

The geological log of crown of cave 29 is presented in plate VII – 126 and the section along the center line is presented in plate VII – 127.

CAVE - 30

This cave forms a part of Jain group of caves and is excavated more than a kilometer away from cave 29, at the northern spur of the ridge. These Jain excavations are numbered from 30 to 34. This cave can be approached by a small foot track from right side of cave 32. This in complete cave is known as 'Chota Kailash' as an attempt was made to imitate the cave 16 (Kailash). The rear portion of the cave is unfinished. This cave is excavated within the hill where the high standing wall of 15 meter is present in the back side of temple. Because of its location and orientation drained water along the hill slopes accumulates and locally water logging conditions are noticed within the left porch and peripheral portion of the cave. This cave consists of a carved rectangular entrance, a courtyard, central hall, and Shrine. There is one cell each on left and right side of Central hall. The left cell is incomplete. Near entrance of cave on right side a horizontal fracture with open joint is noticed and the blocks may dislodge any time. Rock at entrance is highly weathered (Gr.IV) and vesicular in nature. Water seepage is noticed from the fracture of category V present in the crown of entrance (trending $N25^{\circ}E-S25^{\circ}W$ direction) and left corner of central hall. An open water tank is present on left side of courtyard. Major damage is towards outer left portion where a part of facade has fallen. Pillars inside the cave are moderately weathered (Gr.III) at the base. Sculptures on outside walls of cave are moderately weathered and damaged due to micro fractures and weathering. Drained water from hill slopes is found dripping from the walls of cave which are highly weathered (Gr-IV) accompanied by the growth of moss. Infiltrated water along fractured and weathered rock mass above the entrance of

Plate : VII-126

GEOLOGICAL LOG OF CROWN OF CAVE 29 AT ELLORA



INDEX

	SLIGHTLY WEATHERED VESICULAR BASALT
	TRACE OF UNIT CONTACT / SQUEEZE UPS
	TRACE OF CRACKS/ FRACTURES
	WATER SEEPAGE ZONES
	PLASTERED CRACKS
	EDGE OF BROKEN CROWN/ ROCK FALL ZONES
	QUARTZ VEIN
HAZARD GRADATION OF CRACKS	
	CATEGORY I STABLE, HAIRLINE
	CATEGORY II
	CATEGORY III
	CATEGORY IV
	CATEGORY V UNSTABLE OR AREAS WHERE TREATMENT IS REQUIRED
R. L. OF FLOOR: 617.76m R. L. OF CROWN: 623.56m	
M. M. POWAR GEOLOGIST (SR.)	

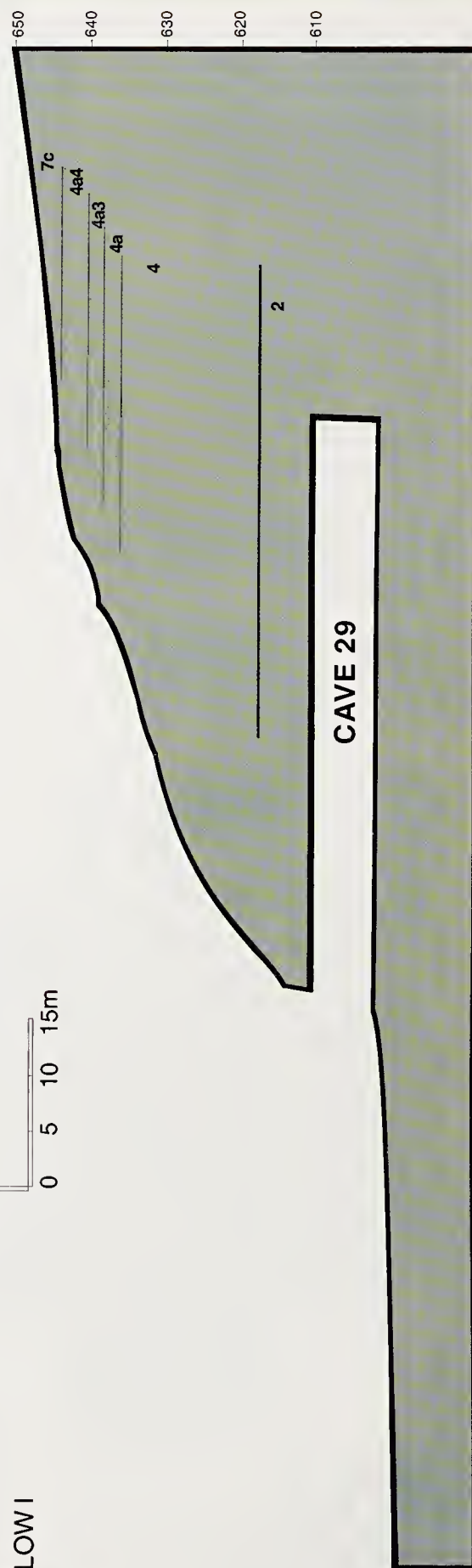
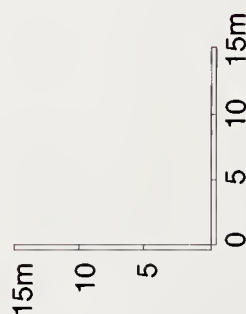


Plate : VII-127

GEOLOGICAL CROSS SECTION ALONG THE CENTRE LINE OF CAVE 29 AT ELLORA

INDEX

- UNIT CONTACT
- FLOW I





cave emerges through cracks in crown, left wall and base of entrance structure. Some chemical treatment is required for cleaning the weathered moss covered portion outside the cave.

Suggested Treatment: (a) Shotcreting of northern (backside) wall and providing drain on top. (b) Shotcreting and crack filling in left front side. (c) Epoxy / polymer coating for weathered rock and cracks. (d) Removal of loose dislodged boulders / rock blocks on back side hill top of cave. (e) Strengthening of damaged pillars. (f) Management of accumulated water in courtyard.

The geological log of crown of cave 30 is presented in plate VII – 128 and the section along the center line is presented in plate VII – 129.

CAVE - 31

This cave is situated towards the right side of cave No. 32 and is almost part of cave 32. It consists of small rectangular hall and a shrine. The walls and shrine are carved with images of Jain lords (Teerthankaras). Two major fractures of category 5 run across the hall trending N10°E to NS and N10°W to N20°W direction respectively. Seepage is noticed along these fracture planes. These fractures continuing with right wall & columns of hall have been recently repaired using cement. Facade of cave consists of highly jointed rocky mass situated on a slopping ground and require treatment. Highly vesicular bands of varying width of 5 to 40 cm is observed on the wall of hall at a level of 1 to 1.5 m from ground level. Rock is moderately weathered (Gr.III) outside the cave. However sculptures & walls inside the cave are slightly weathered (Gr.II). Sculptures have

lost their sharpness and are pitted due to presence of vesicles. Relief joint observed on a slopping ground and require treatment in facade and above the cave lead the infiltrated water from top weathered zone and soil cover to the inside of cave.

The geological log of crown of cave 31 is presented in plate VII – 130.

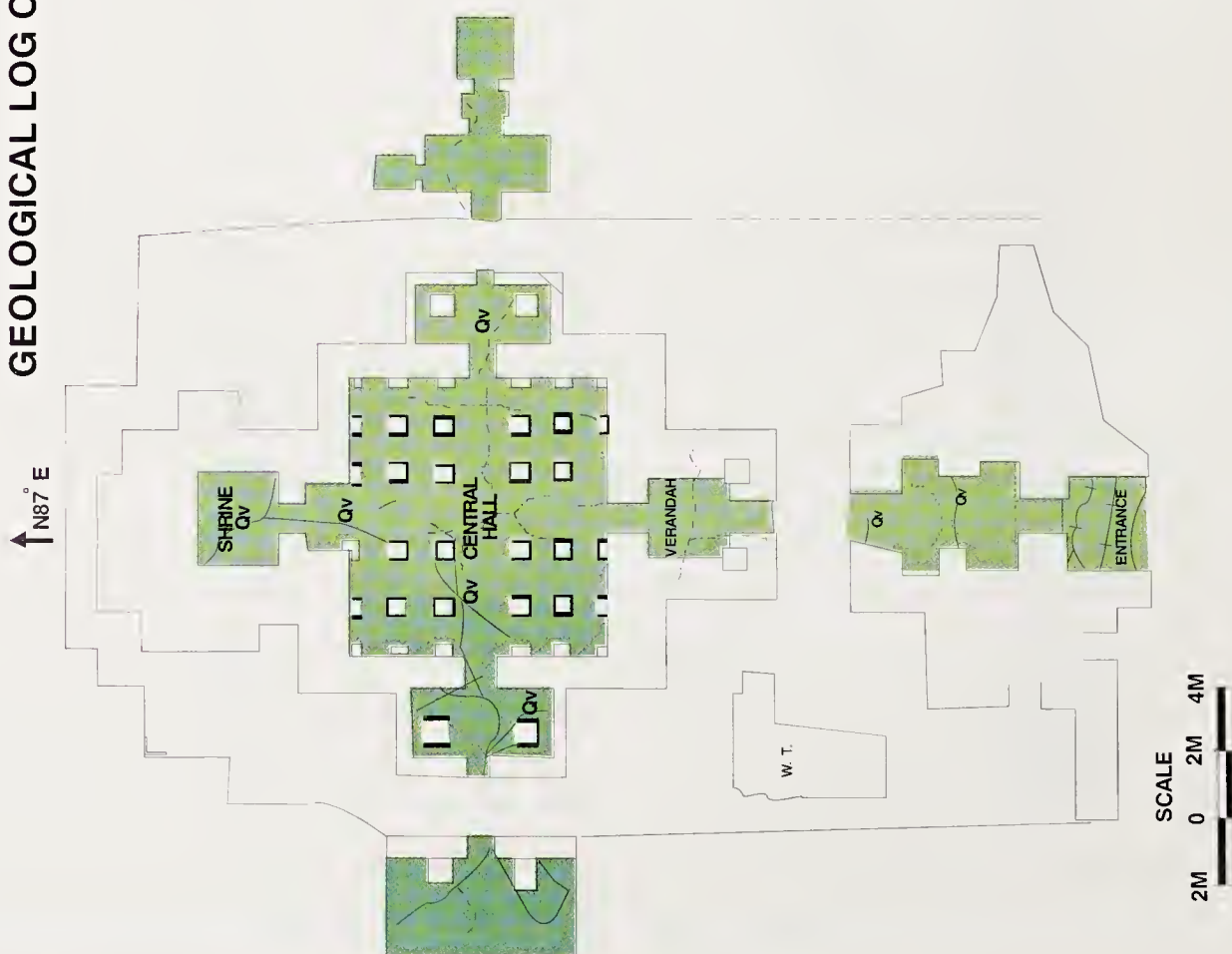
CAVE - 32

LOWER DECK: It is situated on the right center among four Jain caves. This cave is known as 'Indra Sabha' or the 'Assembly hall of king of gods' is a grand two storied temple similar in plan to the Kailash i.e. cave 16 among the Hindu caves. Entrance of the cave is a decorative domal structure with stoned elephant on the right side. A 9.14-meter high reconstructed column, a reminiscent of Kailash is present in the left side of courtyard. Rock containing the elephant sculpture is moderately weathered (Gr.III) with highly vesicular bands ranging from 10 – 40 cm in width. In the center of courtyard there is a rectangular decorative carved structure with its four sides containing images of god Mahavir. The basal portion of all these structures is slightly to moderately (Gr.II/III) weathered and is having many cracks. Some of these cracks are repaired by rock stitching.

In the courtyard there are two cells on the left side and two cells on the right side. On both sides the 2nd cells are at lower levels. A fracture of category 5 trending N30°E-S30°W direction with seepage is noticed on the crown of the 1st left cell. Another fracture of category IV trending N25°W-S25°E with seepage and calcareous encrustation is also observed. Crown of the cell is

Plate : VII-128

GEOLOGICAL LOG OF CROWN OF CAVE 30 AT ELLORA



INDEX

	SLIGHTLY WEATHERED VESICULAR BASALT
	TRACE OF UNIT CONTACT / SQUEEZE UPS
	TRACE OF CRACKS/ FRACTURES
	WATER SEEPAGE ZONES
	PLASTERED CRACKS
	EDGE OF BROKEN CROWN/ ROCK FALL ZONES
	QUARTZ VEIN
HAZARD GRADATION OF CRACKS	
	CATEGORY I STABLE, HAIRLINE
	CATEGORY II
	CATEGORY III
	CATEGORY IV
	CATEGORY V UNSTABLE OR AREAS WHERE TREATMENT IS REQUIRED
R. L. OF FLOOR: 643.31m R. L. OF CROWN: 646.94m	
M. M. POWAR GEOLOGIST (SR.)	

GEOLOGICAL CROSS SECTION ALONG THE CENTRE LINE OF CAVE 30 AT ELLORA

INDEX

UNIT CONTACT

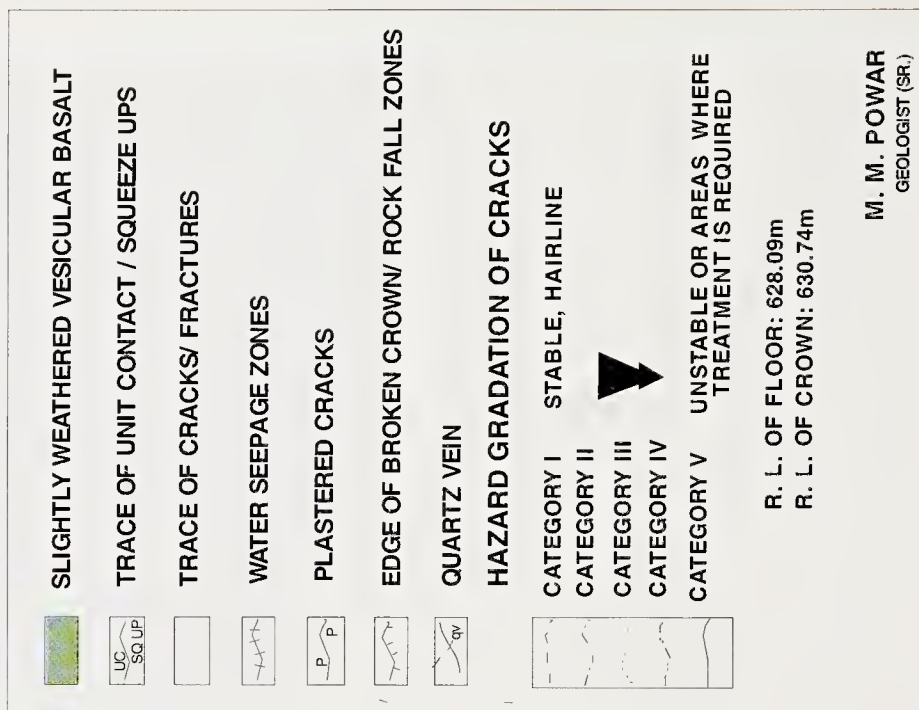
FLOW I



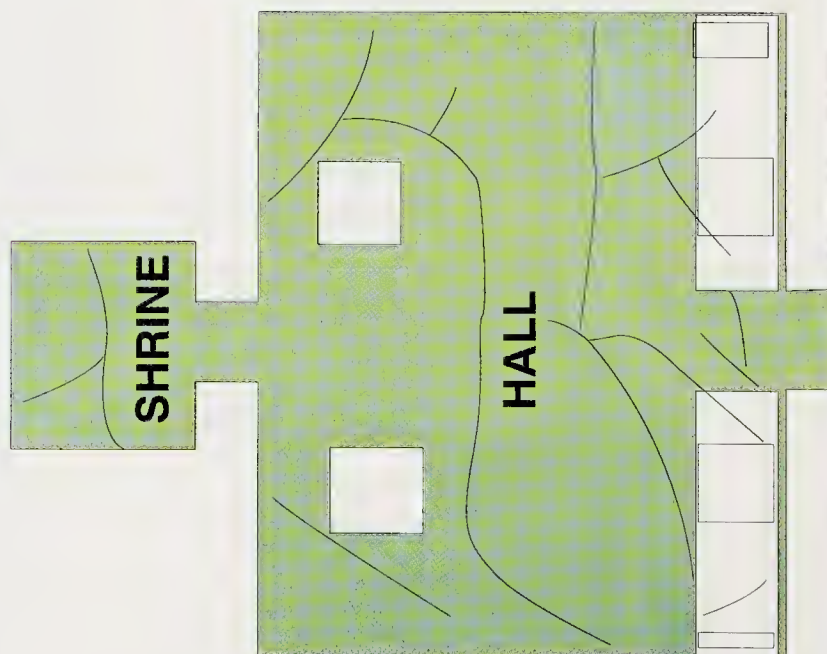
Plate : VII-130

GEOLOGICAL LOG OF CROWN OF CAVE 31 AT ELLORA

INDEX



↑ N85° E



COURTYARD

SCALE

2M 0 2M 4M





covered with plaster probably for painting. This has peeled off at many places. On right side of front wall of shrine in central hall minor rock fall is observed. The sculpture on the right side is damaged due to major joint within sculpture where as on left side the damage is due to water seepage from vertical cracks in crown portion. A small water storage tank (60cm x 30cm) is present on left side of central hall. Water seepage in the form of continuous dripping is noticed from a hole in the crown near 1st right pillar. 2nd right pillar is damaged near the base due to joints. A hole in the wall is observed near the base in right wall and opens in to the 2nd left cell. Along the cracks the rock is moderately weathered (Gr.III) where as inside the cell in central hall and shrine portion, this rock is slightly weathered (Gr.II). Cement plastering of crack is observed.

The crown of 2nd left cell in courtyard is plastered but has peeled off at places. Fine horizontal quartz veins are observed on walls at a height of 55 to 90 cm from ground level and are present through out the cell. Three fractures of category II are observed on the crown of the cell, trending N-S, N70°E – S70°W and N25°W-S25°E respectively. Lower portion on central hall indicates slightly weathered rock and damage to sculptures due to micro fractures. A small cell on top of this cell is unweathered (Gr.I) and no seepage is noticed there.

Right side 1st cell on courtyard is an incomplete excavation where a fracture of category V trending N25°W-S25°E is observed near main switchboard on roof of cell. Water seepage in the form of continuous dripping forming calcareous encrustation is noticed. The two columns of 2nd

right cell in courtyard are in dilapidated condition and crown of the cell is plastered.

There is one cell each on left and right side of verandah and is at higher level than the verandah. A quartz vein is present on the crown of verandah trending N65°E -S65°W direction. Crown of left cell on verandah is plastered with reddish material. Crown of right cell indicates category II crack in verandah and quartz jasper vein trending N20°E -S20°W direction of 1 to 4 cm in width on crown of shrine. Crack of category III, trending N15°W-S15°E direction filled with quartz is observed on the crown of left incomplete cell.

A crack of category IV is observed in the crown portion of central hall trending N20°W-S20°E, running from right side of front aisle to central hall upto back aisle. The spacing varies from 1 to 2 cm. Fracture of category II filled with quartz vein is noticed trending N40°E - S40°W direction. Minor fractures of category I & II are also noticed on crown portion of central hall.

UPPER DECK: A flight of stairs in right side of verandah of ground floor leads to the upper deck. It consists of central hall, and small entrances with cells each on left and right side connecting to pillared complexes. The crown of central hall in upper deck has colorful paintings. These paintings have become hazy due to weathering. Fracture of width 2 -3cm filled with quartz and jasper, trending N60°E-S60°W is present in the front aisle left corner of crown in central hall. Crack of category V having a width of 5 – 6 cm with varying trend of N28°E to N40°W / 90° filled lenticular vugs of quartz is observed in the small cell connecting to right complex. Seepage



accompanied with formation of stalactite is observed inside this cell. Facade of right side complex has developed horizontal cracks along weathered (Gr.III) unit contact where dripping of water is also noticed. Wall is moist due to infiltrated water. The rock is moderately weathered (Gr.III) along the cracks and sculptures are damaged due to micro fractures and water action.

In left complex a crack of category III trending N55°E-S55°W having a width of 2-3 mm is noticed where water seepage in form of continuous dripping is observed along with deposition of calcium carbonate. Sculptures are slightly weathered (Gr.II) and are damaged due to micro fractures and joints. Cracks are repaired with cement. Rock in rest of cave is unweathered.

Suggested Treatment: (a) Removing of existing gunited portion and relaying of shotcrete upto retaining wall and providing drain upto bedrock. (b) Diversion of surface water towards southern side drain of cave 32B. (c) Filling of cavity on right side facade.

The geological log of crown of cave 32 is presented in plates VII – 131, 132 & 133 and the section along the center line is presented in plate VII – 134.

CAVE - 32B

This cave is situated in the backside of cave 32. It can be approached by stairs in the right of cave 31. This cave consists of courtyard and hall / shrine. This is an incomplete cave where unfinished excavations are present on both left and right side of the hall. Sculptures carved above the entrance have lost their sharpness and are damaged

due to weathering (Gr.II). A fracture of category V is observed on the crown portion of hall with varying trend of N10°W to N50°W direction. Seepage and calcareous encrustations are observed along this fracture plane. Quartz vein having a width of 2 – 4 cm emplaced along a joint / fracture plane of category IV is noticed in the right side crown portion of hall. Another quartz vein trending N15°E – S15°W / 90° of varying width of 1 to 5 cm is noticed in the left side crown portion of hall. In the courtyard water logging conditions and mud deposition has been observed locally due to accumulation of drained water.

Suggested Treatment: (a) Cleaning and lining of existing drainage channel. (b) Removal of existing gunited surface and relaying of shotcrete further ahead of retaining wall and providing drainage leading to right side. (c) Epoxy / polymer coating for weathered rock and cracks. (d) Drain behind the retaining wall is to be deepen upto bedrock and widen. (e) Provision of weep holes.

CAVE – 33

LOWER DECK: This cave is known as 'Jagnath sabha' and belongs to Jain religion. There is a passage or entrance connecting 1st floor of cave 32 to 1st floor of cave 33. Cave 33 consists of a small incomplete cell on the right side and two decks ground floor and 1st floor in central portion and a cave to its left side.

In the central hall of ground floor a major quartz-jasper-flint vein trending N57°W-67° NE is observed having a width of 2 to 10 cm running from right corner of Central hall to left corner near shrine portion. Number of cracks of category III and IV are observed on the crown portion of

Plate : VII-131

GEOLOGICAL LOG OF CROWN OF CAVE 32 (LOWER DECK) AT ELLORA

SHEET - I

INDEX

	SLIGHTLY WEATHERED VESICULAR BASALT
	TRACE OF UNIT CONTACT / SQUEEZE UPS
	TRACE OF CRACKS/ FRACTURES
	WATER SEEPAGE ZONES
	PLASTERED CRACKS
	EDGE OF BROKEN CROWN/ ROCK FALL ZONES
	QUARTZ VEIN
HAZARD GRADATION OF CRACKS	
	CATEGORY I STABLE, HAIRLINE
	CATEGORY II
	CATEGORY III
	CATEGORY IV
	CATEGORY V UNSTABLE OR AREAS WHERE TREATMENT IS REQUIRED
R. L. OF FLOOR: 628.09m R. L. OF CROWN: 630.74m M. M. POWAR GEOLOGIST (SR.)	

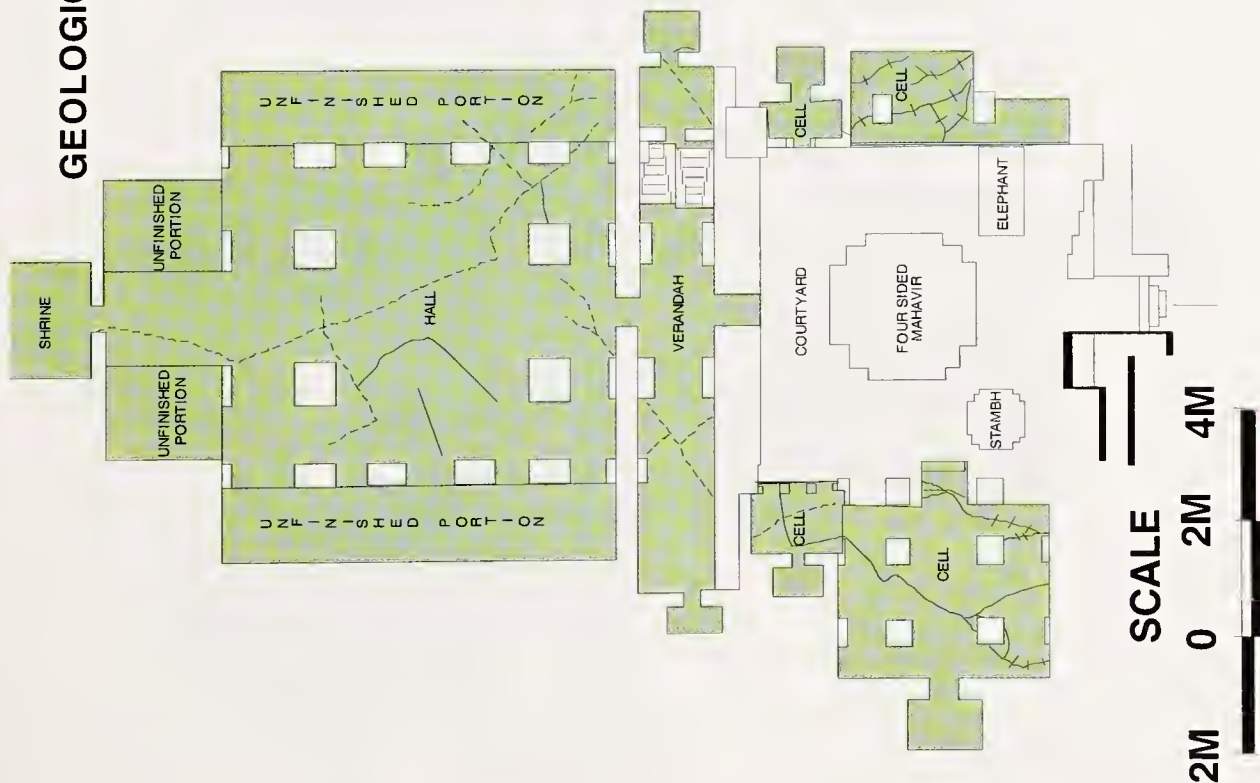




Plate : VII-132

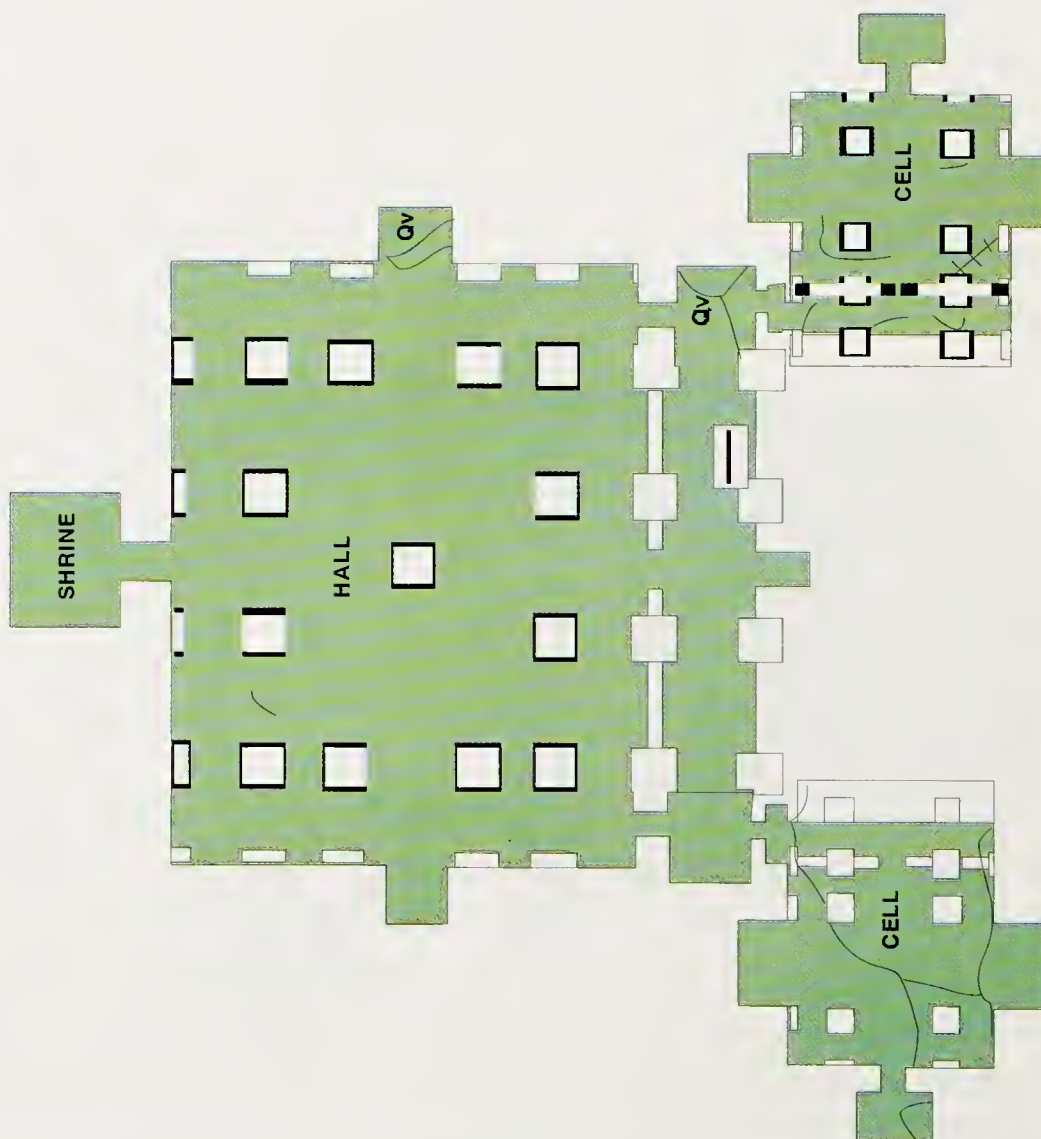
GEOLOGICAL LOG OF CROWN OF CAVE 32 (UPPER DECK) AT ELLORA

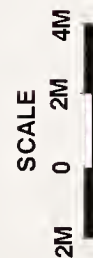
SHEET - II



INDEX

	SLIGHTLY WEATHERED VESICULAR BASALT
	TRACE OF UNIT CONTACT / SQUEEZE UPS
	TRACE OF CRACKS/ FRACTURES
	WATER SEEPAGE ZONES
	PLASTERED CRACKS
	EDGE OF BROKEN CROWN/ ROCK FALL ZONES
	QUARTZ VEIN
HAZARD GRADATION OF CRACKS	
	CATEGORY I STABLE, HAIRLINE
	CATEGORY II
	CATEGORY III
	CATEGORY IV
	CATEGORY V UNSTABLE OR AREAS WHERE TREATMENT IS REQUIRED
R. L. OF FLOOR: 637.23m R. L. OF CROWN: 641.03m	
M. M. POWAR GEOLOGIST (SR.)	





SLIGHTLY WEATHERED VESICULAR BASALT

TRACE OF UNIT CONTACT / SQUEEZE UPS

TRACE OF CRACKS/ FRACTURES

WATER SEEPAGE ZONES

PLASTERED CRACKS

EDGE OF BROKEN CROWN/ ROCK FALL ZONES

QUARTZ VEIN

HAZARD GRADATION OF CRACKS

CATEGORY I STABLE, HAIRLINE

CATEGORY II

CATEGORY III

CATEGORY IV

CATEGORY V UNSTABLE OR AREAS WHERE TREATMENT IS REQUIRED

R. L. OF FLOOR: 637.23m

R. L. OF CROWN: 641.03m

M. M. POWAR
GEOLOGIST (SR.)

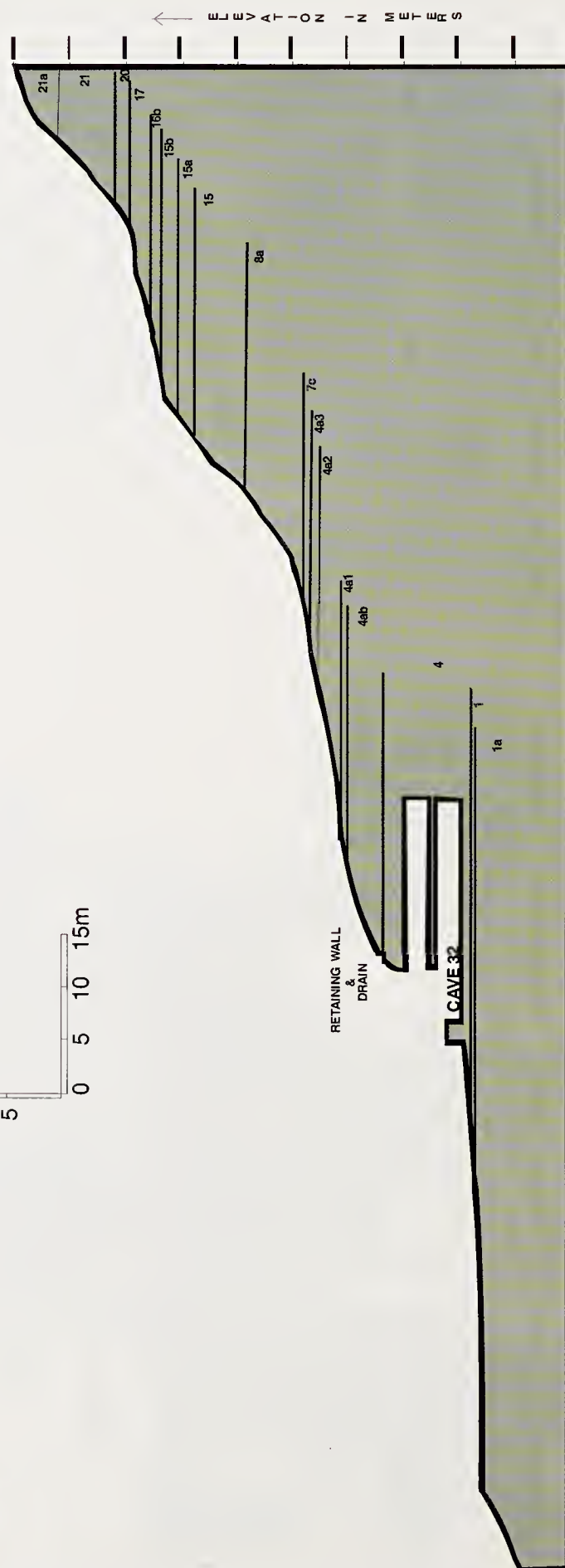
Plate : VII-134

GEOLOGICAL CROSS SECTION ALONG THE CENTRE LINE OF CAVE 32 AT ELLORA

INDEX

UNIT CONTACT

FLOW I





central hall. Cracks are also observed in the facade of cave. In left cave vertical cracks grading II to IV are observed in the crown portion of central hall. Crack of category V trending N35°E / S35°W direction is noticed on crown of central hall where water seepage in form of continuous dripping is observed.

Facade of right cell contains number of fractures on an unstable rock mass on sloping ground. Inside the cell a category of V crack trending N20°W to N65°E / 90° direction indicate heavy water seepage in form of continuous dripping, and formation of stalactite. A walled column constructed recently at the entrance of the cell has also developed some cracks.

UPPER DECK: Flight of stairs on the right side in courtyard of ground floor leads to the upper deck of cave 33. In the stairs a crack is observed in the ceiling portion where seepage and deposition of calcium carbonate (stalactite) were noted. Upper deck consists of 4 aisles, central hall, a shrine and incomplete cells each on left and right side. Small entrance made through right cell leads to the upper deck of cave 32. Crown portion of central hall of 1st floor is plastered and painted. From most of places plaster has fallen and original paintings can be seen in few location only. Fracture of category II and small quartz vein are observed in the crown portion of central hall and right cell. Crack of category V is noticed in the corner of right aisle where water seepage is noticed (Plate – 137).

Suggested Treatment : (a) Removing of existing gunited surface and relaying by shotcrete upto retaining wall. (b) Providing drain (deep channel)

with weep holes (up slope side) upto bedrock. (c) Improving existing water drains (two) from hill slopes by lining or making impervious and draining the water ahead of cave 34. (d) Removal of rolled boulders on top of cave.

The geological log of crown of cave 33 is presented in plate VII–135 and 136.

CAVE - 34

It is the last excavated Jain cave in the Ellora complex. It consists of a courtyard, a verandah, a central hall and a shrine. Wall portion between cave 33 and 34 is broken. Facade is highly jointed and has developed many cracks. Rain water draining from hill slopes accumulates in the right hand corner near entrance where water tank is present. Crown of central hall indicate a crack of category V in left corner trending N35°E / 90° where seepage is noticed. Unit contact is observed in right side of crown of central hall. Along the unit contact, the rock is weathered and having seepage points. Quartz vein of a width of 2cm is present in the crown of central hall trending N35°W to N55°W/90°. Two fractures of category V are also observed on Central hall trending N35°E and N15°W/90° respectively. The rock is slightly weathered (Gr.II) and sculptures are damaged due to microfractures and joints. The rock cover of the cave is very thin (about 1.5 to 2m). Roof covered with concert is noticed.

Suggested Treatment : (a) Removing of existing gunited surface and relaying by shotcrete upto retaining wall. (b) Providing drain (deep channel) with weep holes (up slope side) upto bedrock.

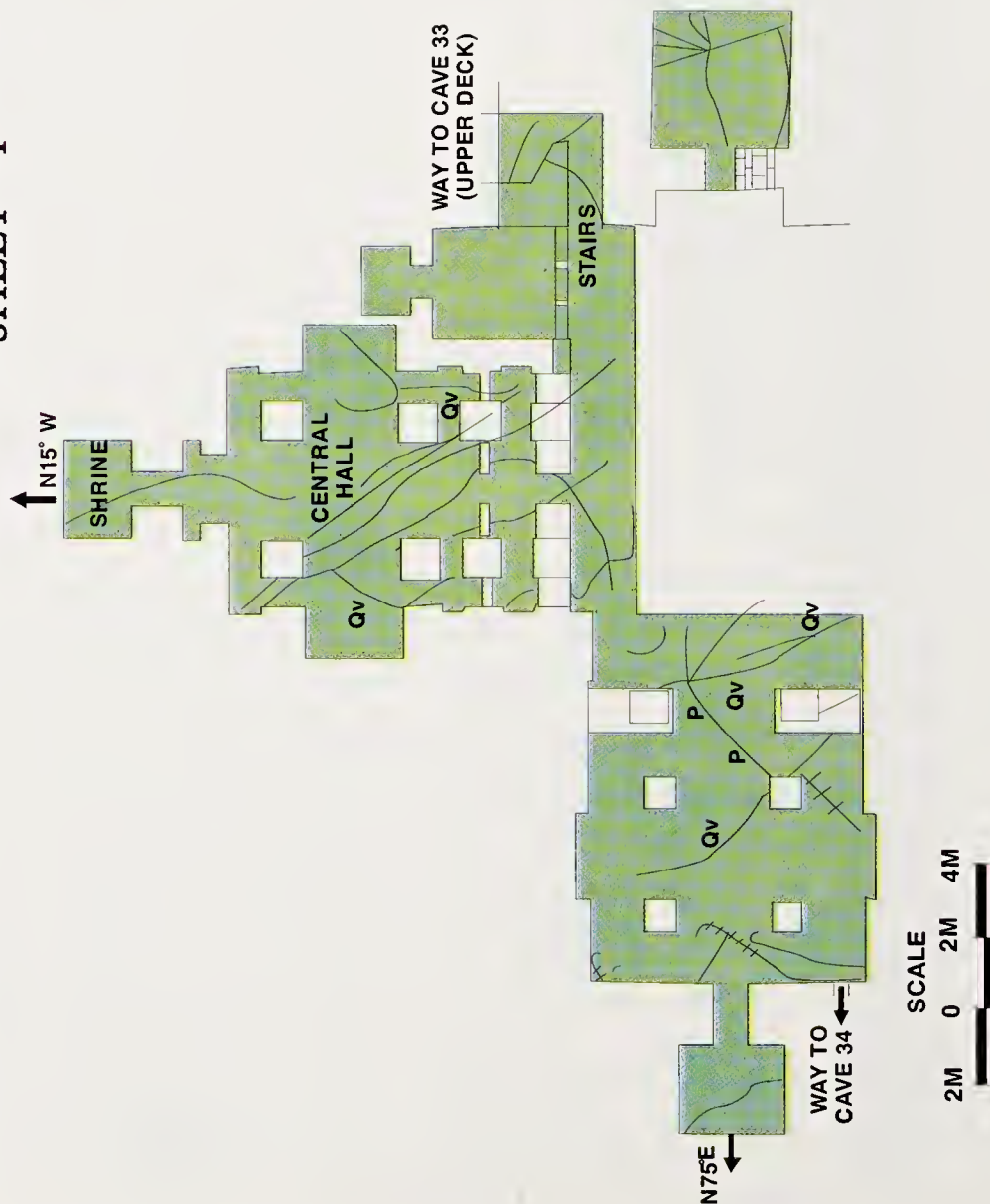
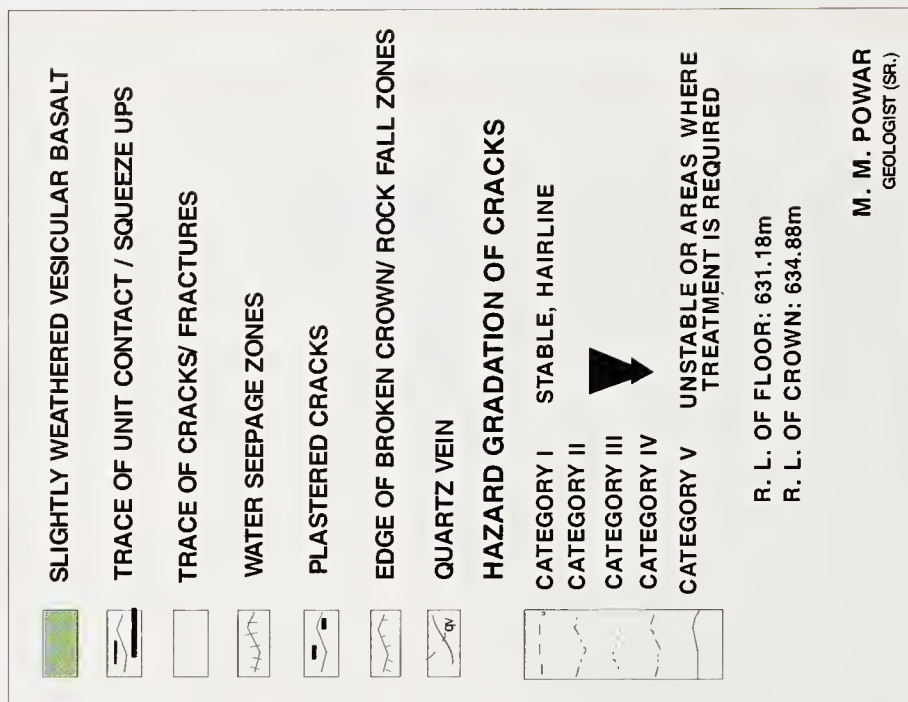
The geological log of crown of cave 34 is presented in plate VII – 137.

Plate : VII-135

GEOLOGICAL LOG OF CROWN OF CAVE 33 (GROUND FLOOR) AT ELLORA

SHEET - I

INDEX



GEOLOGICAL LOG OF CROWN OF CAVE 33 (UPPER DECK) AT ELLORA

SHEET - II

INDEX

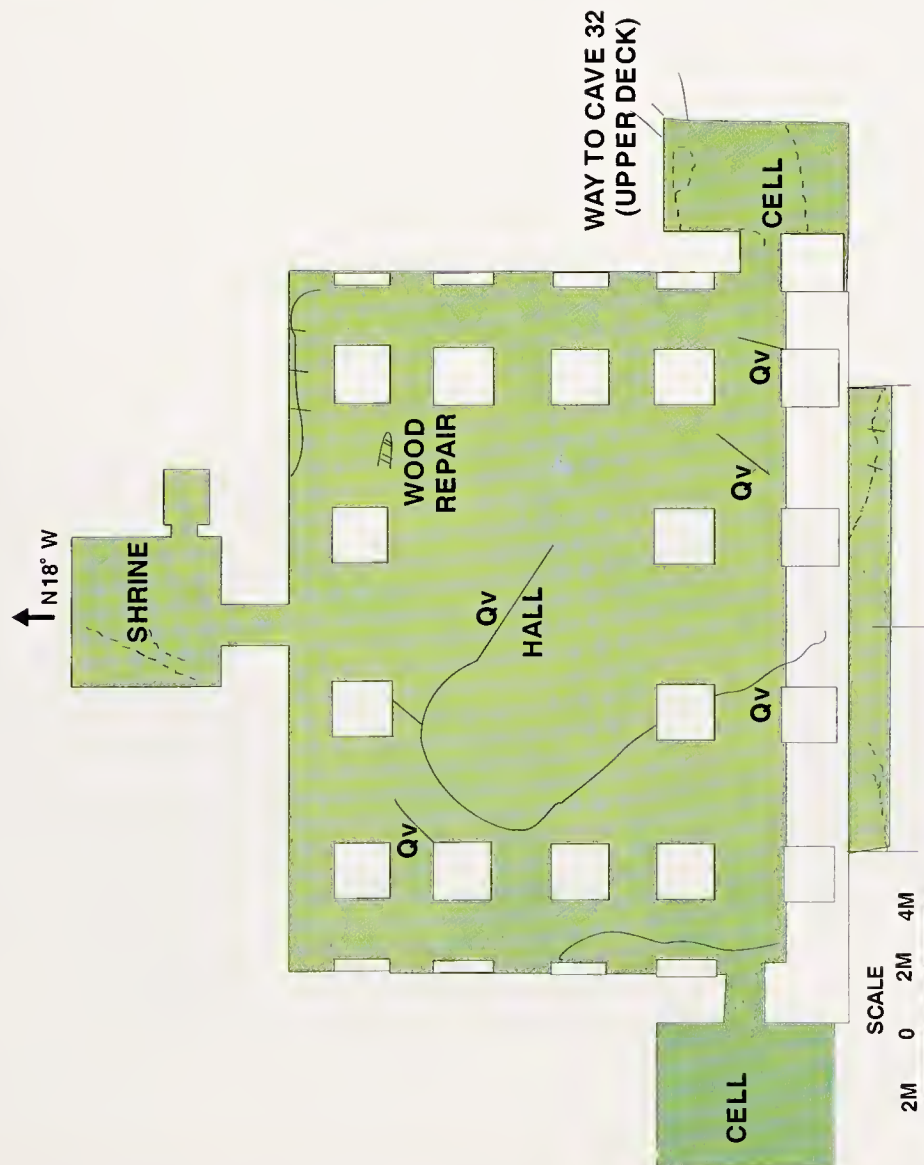
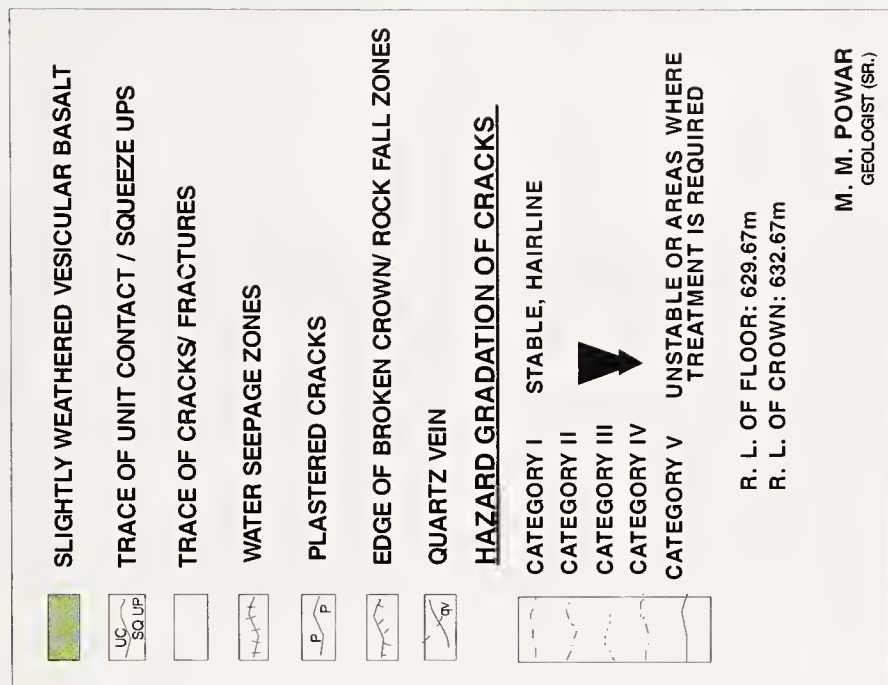
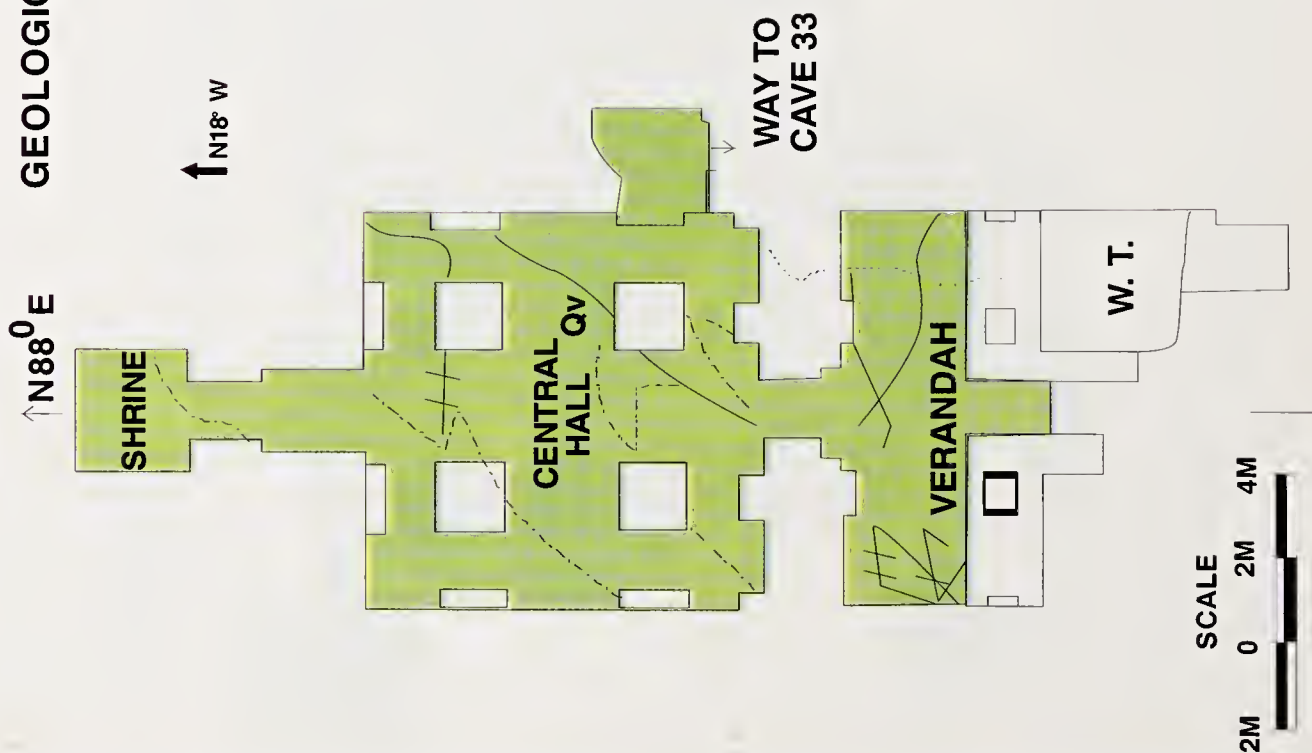




Plate : VII-137

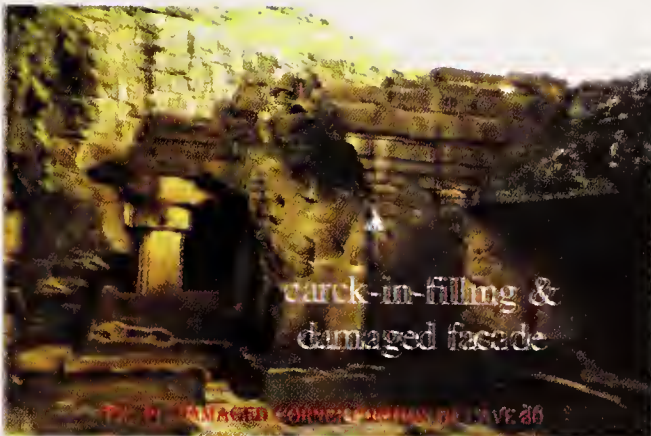
GEOLOGICAL LOG OF CROWN OF CAVE 34 AT ELLORA



INDEX

	SLIGHTLY WEATHERED VESICULAR BASALT
	TRACE OF UNIT CONTACT / SQUEEZE UPS
	TRACE OF CRACKS/ FRACTURES
	WATER SEEPAGE ZONES
	PLASTERED CRACKS
	EDGE OF BROKEN CROWN/ ROCK FALL ZONES
	QUARTZ VEIN
HAZARD GRADATION OF CRACKS	
	CATEGORY I STABLE, HAIRLINE
	CATEGORY II
	CATEGORY III
	CATEGORY IV
	CATEGORY V UNSTABLE OR AREAS WHERE TREATMENT IS REQUIRED
R. L. OF FLOOR: 630.20m	
R. L. OF CROWN: 633.30m	
M. M. POWAR GEOLOGIST (SR.)	

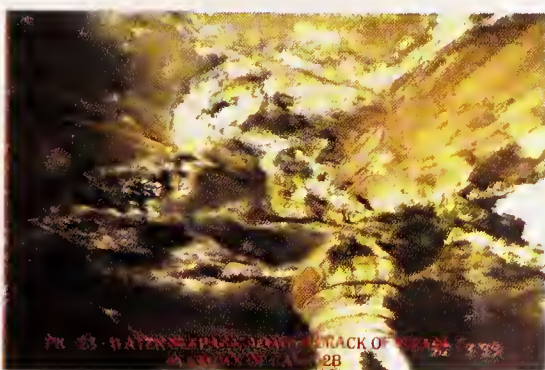
Plate : VII-138



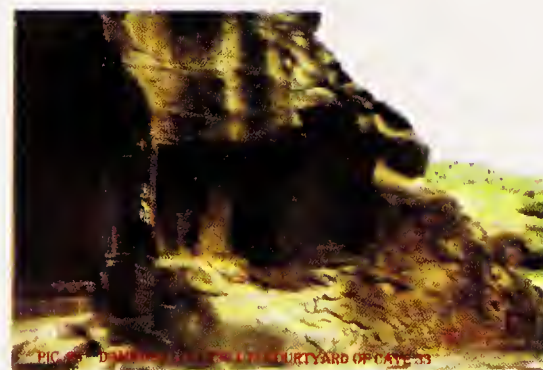
Cave 30, Damaged part of façade and crack-in-filling along a joint plane.



Cave 32, Cracks at the base of stambh repaired with rock stitching.



Cave 32B, Roof of cave affected by water seepage along fracture of grade 5.



Cave 33, Damaged right cell & walled column where seepage noticed from roof of cell.

SURFACE WATER MANAGEMENT

As a part of geotechnical studies and seepage assessment in the caves the surface water management studies were carried out during the monsoon and post monsoon periods. The studies include the evaluation of surface drainages around the cave areas and the seepages noticed in the different caves.

The different contributory factors to the seepages in the caves were assessed and effective remedial measures in the form of surface water management have been proposed.

CONTRIBUTORY FACTORS TO SEEPAGE

Almost in all caves above the cave levels, Longitudinal contour drains (LD) have been constructed to divert the water to the inter cave depressions.

Numbers of micro-scarps having 1-2m height are present in the upper slope areas. Accumulations of scree materials (silty soil, pebbles and boulders) of thickness 0.1m to 0.5m exist at the foot of these micro scarps. During monsoon, they hold water and release progressively, thereby charging such zones from higher to lower levels upto the cave frontals due to gradient as a result of which the water reaches the caves/facades, causing seepage. This forms a major contributing factor to the seepages in the caves.

Four major perennial cross drainages, nalas (N1 to N4) with supporting minor ones drain the cave surroundings.

The N1 drainage flows over cave 5 and 6 and has a flow during most part of the year. The nala bed has number of potholes above the cave area. It has a fall of 24m between cave No.5 and 6. The

fall has been extended beyond the cave frontal by constructing a RCC cantilever structure of about 6 m. This fall erodes the toe support of the hill/caves between 4 and 8, which may endanger the stability of the caves located above it.

The N2 nala flows in the inter cave area of cave 16 and 17 (closer to cave 16). The flow in the nala is noticed during most part of the year. This nala makes a fall of 22m from 630m $\pm$ 2m above msl elevation.

The N3 nala flows across the inter cave area between caves 24 and 25. It has got a cascading flow with minor escarpments of 4-5m in the upper slope area and has a fall of about 10m from 620m $\pm$ 2m elevation.

The N4 nala forms the major drainage system in the area flowing across the inter cave areas of cave 27 and 29 making a fall of 37m from 620m $\pm$ 5m elevation. This nala has water flow for most part of the year. This plunging fall created a deep pool at the foot of the retreating scarp, which is also responsible for damaging the cave 28. A number of large potholes with depth varying between 2 and 10m, which are reported to be interconnected at places are present in the nala bed.

A 2-3m wide zone of relief joints, other cooling joints, cracks and unit contacts present in most of the cave frontals form the avenue for seepages in the verandahs of the caves.

Most of the drains are constructed with stone massioneries in the topsoil and are not housed in the bedrock. These drains are in damaged condition, as a result of which water starts heading up on the upstream side and bypasses the drains and contributes to accentuated seepage through the zone of relief/cooling joints/cracks, unit contacts etc. in the cave frontals.



SURFACE WATER MANAGEMENT AND SEEPAGE CONTROL

Based on the evaluation of the existing surface water management system and seepages problems in the caves, the following recommendations are made.

- 1) The area between the Longitudinal contour drains (LD) and the cut edge of the caves should be scrapped off the soil and the surface be made impervious by shotcreting to seal the openings/joints etc. The shortcrete area must be covered by relaying of the scrapped soil for turffing to regain the natural look of the slopes.
- 2) The inter cave areas as mentioned below, need to be treated as mentioned in point (1) to seal openings/joints ect.
 - a) Between caves 10-11, 11-12.
 - b) Around cave 15.
 - c) On either sides of cave 16.
 - d) Between caves 17A and 18, around 19A, 19B and 20, 20 and 21, around 22, 23, 24 and 24A.
 - e) Between caves 32, 33 and 34.
- 3) The nala bed of N1 need to be sealed with shotcrete upto the cave limits. The potholes in this reach need to be filled up with plain concrete before shotcreting.
- 4) The damaged longitudinal contour drains are to be repaired immediately and housed in bedrock profile suitably wherever necessary. The upper wall/slope side of the drains be constructed with porous concrete and provided with weep/drain holes so that the water in the soil on the upper slope side gets discharged into the drain and drained off.

- 5) The following new longitudinal contour drains are proposed for construction in the slope areas above the caves/ or above the shotcreted portion to collect the surface water and to drain them off, thereby cutting of the surface water reaching the cave frontals/facades to the maximum possible extent. The gradient to be decided during the time of execution at the proposed location, either to have a single gradient or from one mid-point/suitable point, gradient towards either sides as suitable. These drains are to be constructed with porous concrete with weep/drain holes on the upper wall/slope side, so that the surface water is collected and drained off into the natural nalas/ depressions away from the caves. These drains will also intercept the natural cross nalas if any and drain off the discharge.

PROPOSED LONGITUDINAL CONTOUR DRAINS

- (i) A Longitudinal contour drain (LD1) between level 640-645 m above msl above the shotcrete portion, above caves 1-5. This may have a gradient from a mid-point/suitable point to either sides discharging into nala (N1) on the northern end and to the nala on southern end.
- ii) Longitudinal contour drain (LD2) above the shotcrete portion above caves 11 to 14 with gradient on either sides, discharging the water in the inter cave area between 14 and 15 in the northwestern end into the already existing drain in the southeastern end.
- iii) Longitudinal contour drain (LD3) at the base of the mound and above the shotcrete portion above the annex caves of cave 16.



- iv) Longitudinal contour drain (LD4) on the northern side of cave 16 (from DT-15, extending the existing drain) with gradient to discharge the water into the N2 nala.
- v) Longitudinal contour drain (LD5) above the shotcrete portion above cave 24.
- vi) Longitudinal contour drain (LD6) between 630-635m above msl, above caves 23-24A with gradient on either side from a midpoint/suitable point, discharging the water into the natural nalas on either side (northwestern and southeastern end).
- vii) Longitudinal contour drain (LD7) between 645-650m above msl, above caves 25 to 27 with gradient on either sides from a midpoint/suitable point to discharge the water into the natural cross nalas on either sides.
- viii) Longitudinal contour drain (LD8) between 640-645m above msl, above Ganesh group of caves on the left bank of N4 nala, with gradient on either sides (towards northeastern and southwestern end) discharging the water into the N4 nala.
- ix) Longitudinal contour drain (LD9) between 645-650m above msl, above Ganesh group of caves on the right bank of N4 nala. This drain will also have gradient on either sides from a midpoint/suitable point, to discharge the water into the N4 nala in the eastern end and into the cross nala in the western end.
- x) Longitudinal contour drain (LD10) between 650-655m above msl, above caves 30A to 34. This drain will have gradient on either side from a midpoint/suitable point to discharge the water into the cross nalas in the eastern and western end.

TABLE VII-7: DAMAGE ASSESSMENT AND SUGGESTED REMEDIAL MEASURES AT ELLORA CAVES

Cave	Location	Structural Adjustment		Effect On Sculptures/ Paintings	Weathering Grade	Anthropogenic Damage	Biogenic Damage	Seepage Related Damage
		Already Completed	Potential					
Cave 1	Facade	Development of negative Slope	Zone of rock fall	-	III to II	-	Moss & small plants	Water Seepage (WS)
	Verandah, portico	Completely destroyed	-	-	IV	-	-	-
	Hall	Pillars collapsed	Loose blocks on crown	-	III to I	-	-	WS + calc coatings
Suggested Treatment: Reinforced shotcrete with rock bolts above cave 1& 2 and selective shotcrete near the top of edge. Provision of windows and drainage at places. Scraping of the top surface to expose fresh rock up to an area of 20m from the edge, followed by shotcreting the surface. Stripping of soil in this zone followed by laying of an impervious layer (geo synthetic or shotcrete) and later followed by relaying of the stripped soil with grass cover will adequately take care of the water seepage. A drain should be constructed at the upper end of the shotcreted zone and which should be embedded in bedrock. Bolting of the loose blocks on the crown of cave 1. Load tests to be carried out in caves 1, in view of the large unsupported spans.								
Cave 2	Facade	Development of negative slope	Zone of rock fall	-	III to II	-	Moss & small plants	WS
	Hall	Lower part weathered along unit contact	-	-	II to I	-	-	WS
Suggested Treatment: Reinforced shotcrete with rock bolts above cave 1& 2 and selective shotcrete near the top of edge. Provision of windows and drainage at places. Scraping of the top surface to expose fresh rock up to an area of 20m from the edge, followed by shotcreting the surface. Stripping of soil in this zone followed by laying of an impervious layer (geo synthetic or shotcrete) and later followed by relaying of the stripped soil with grass cover will adequately take care of the water seepage. A drain should be constructed at the upper end of the shotcreted zone and which should be embedded in bedrock. Polymer filling of the cavity in the right gallery.								
Cave 3	Outer verandah + cells	Destroyed	-	-	II	-	-	-
	Outer wall on right, hall	Destroyed along with portion of the crown of hall	-	-	II to I	-	-	-
Suggested Treatment: Reinforced shotcrete with rock bolts above cave 3 and selective shotcrete near the top of edge. Provision of windows and drainage at places. Scraping of the top surface to expose fresh rock up to an area of 20m from the edge, followed by shotcreting the surface. Stripping of soil in this zone followed by laying of an impervious layer (geo synthetic or shotcrete) and later followed by relaying of the stripped soil with grass cover will adequately take care of the water seepage. A drain should be constructed at the upper end of the shotcreted zone and which should be embedded in bedrock.								

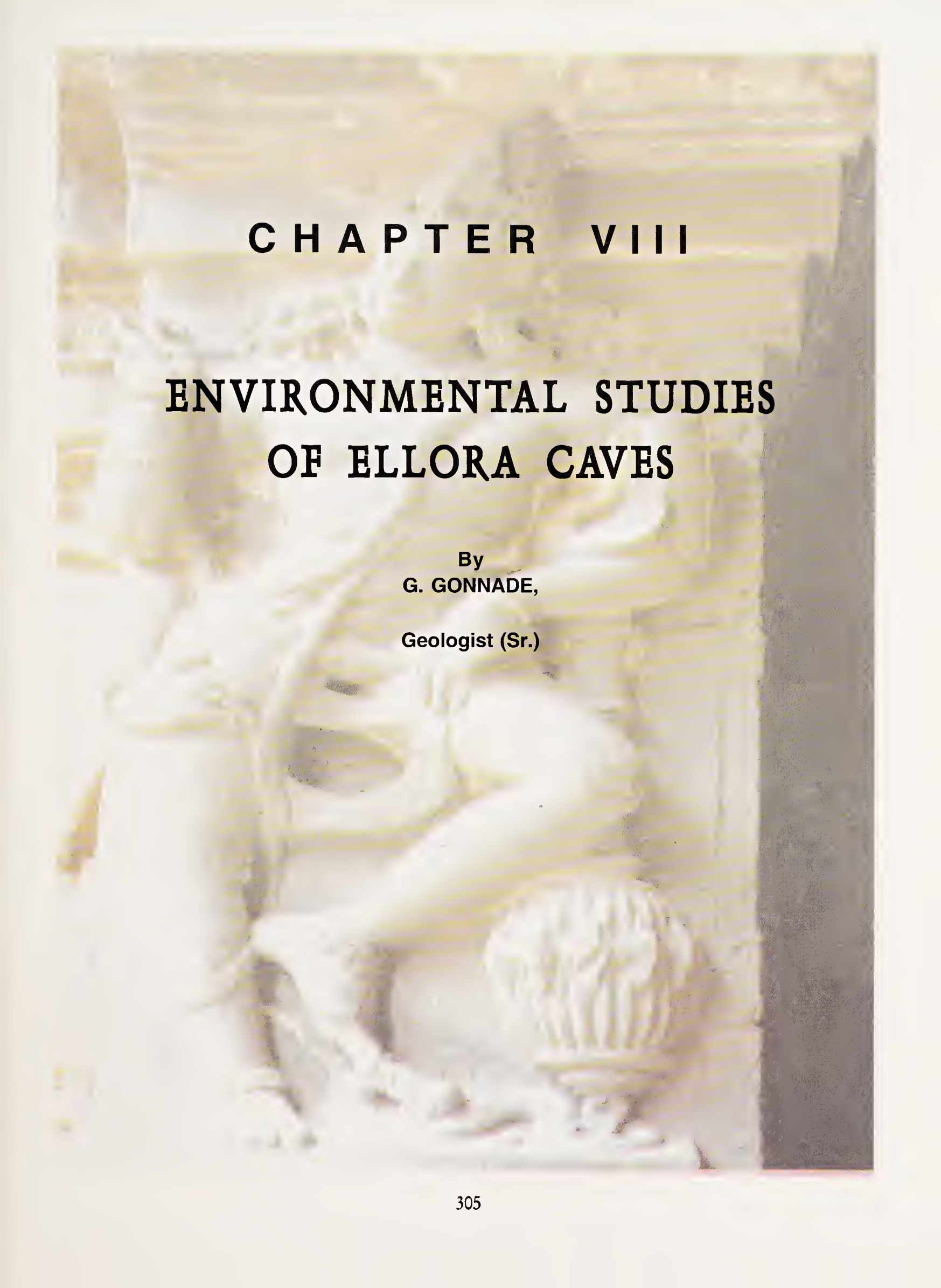
Cave 4	Facade		Zone of rock fall	-	II to I	-	-	-
	Outer part of cave on lower deck	Part of hall & verandah destroyed	-	-	II to I	-	-	-
	Outer part of cave on upper deck	Outer cells, walkway & shrine collapsed	-	-	II to I	-	-	W/S
	Facade		Zone of rock fall	-	II to I	-	-	-
	Extended floor of upper deck		Zone of collapse	-	-	-	-	-
Suggested Treatment: Reinforced shotcrete with rock bolts above cave 4 and selective shotcrete near the top of edge. Provision of windows and drainage at places. Scraping of the top surface to expose fresh rock up to an area of 20m from the edge, followed by shotcreting the surface. Stripping of soil in this zone followed by laying of an impervious layer (geo synthetic or shotcrete) and later followed by relaying of the stripped soil with grass cover will adequately take care of the water seepage. A drain should be constructed at the upper end of the shotcreted zone and which should be embedded in bedrock. Two pillars and a beam may have to be constructed on the lower deck to check toppling failure.								
Cave 5	Outer verandah & front aisle	Crown of front aisle cell destroyed, outer verandah destroyed	-	-	II to I	-	-	-
	Hall	-	Potential zone of rock fall in right aisle	-	II to I	-	-	-
	Pillars in hall	Most pillars renovated	-	-	II to I	-	-	-
Suggested Treatment: Filling up of potholes and pools up to the waterfall in the major nalla above cave 5. Lining of the central 5 m of the nalla channel over which perennial flow is observed. Provision of an iron barrier 20m from the edge to catch rolling boulders. Reinforced shotcrete with galvanized wire below cave.								
Cave 6	Verandah & cell	Collapsed	-	-	II to I	-	-	-
	Central Hall	-	Potential zone de-slaking	-	II to I	-	-	-
Suggested Treatment: Plain shotcrete and rock bolt above cave 6. Construction of a suitable structure to provide support from below should be designed in consultation with a structural engineer.								
Cave 7	Outer structures	Collapsed	-	-	II to I	-	-	-
	Hall	Part of crown & beam have collapsed			II to I	-	-	-
Suggested Treatment: Shotcreting of the crown of the cave to arrest flaking.								
Cave 8	Cell on left of hall	Wide open crack	-	-	II to I	-	-	-
	Outer hall	-	Zone of de-slaking	-	II to I	-	-	-
Suggested Treatment: Rock bolting to stabilize the de-slaking block								
Cave 9	Facade	Rock has been broken	-	-	II to I	-	-	-
Suggested Treatment: Shotcrete of the facade to be extended up to 5 m from the top. The existing drain should be modified and should be extended up to bedrock level. A new drain above the existing drain may be necessary.								

CAVE 10	Façade	Beams & rafters partially destroyed	-		-	II to I		WS
Lower deck	Left verandah & cell		Zone of rock fall		-	II to I		
Lower deck	Right verandah & cell	Moderately weathered	-		-	II to I		WS
Upper deck	Left verandah & cell	-	Zone of rock fall		-	II to I		WS
	Right verandah & cell	-	Zone of rock fall		-	II to I		WS
	Staircase to upper deck	Moderately weathered						WS
Suggested Treatment: Protection of beam/ Rafters on façade by shotcreting and micro stitching. Rock bolting and selective shotcreting on crown of cell on left verandah of lower deck and also part of the verandah near the staircase. Selective shotcreting on crown right verandah of lower deck and cell. Micro stitching of loose rock. Repairing of crown of outer two cells on right side of upper deck. Removing of old guniting and fresh shotcreting up to 15 m from the edge. The shotcrete zone to be merged with the existing drain.								
CAVE 11	Façade Cell & water tank on left of courtyard	Part of facade collapsed	Zone of rock fall					
Suggested Treatment: Shotcreting of the façade and extending it up to 20 m on the top keeping the existing drain. A top drain above the shotcrete to be provided. Shotcreting of the crown of the cell on the left of the courtyard. Training of the nalla between caves 11 & 12.								
CAVE 12	Façade Cell on right wall of courtyard	Marred by rock fall	Zone of rock fall					
	6th - 7 th pillar of outer row on top deck	Accentuated weathering along unit contact						
Suggested Treatment: Shotcreting of the façade and extending it up to 20 m on the top keeping the existing drain. A top drain above the shotcrete to be provided.								
CAVE 13	Outer structures Hall	Completely destroyed Fractures on crown						
Suggested Treatment: Reinforced shotcrete with provision of drainage holes in the negative slope above caves 13 & 14. Plain shotcrete below cave 13 and above caves 13& 14. Shotcrete to be extended for 20 m on top. Top drain to be constructed and end of shotcrete discharge to be led to nalla above 14. Training & lining of nalla.								
CAVE 14	Façade							
	Outer structures	Completely destroyed						
	Outer beam	Moderately weathered						

Suggested Treatment: Reinforced shotcrete with provision of drainage holes in the negative slope above caves 13 & 14. Plain shotcrete below cave 13 and above caves 13 & 14. Shotcrete to be extended for 20 m on top. Top drain to be constructed and end of shotcrete discharge to be led to nalla above 14. Training & lining of nalla									
Cave 15	Facade Cell & shrine on left of Mandapa	Marred by rock fall Fractures on crown							
	Cell & water tank on right wall of courtyard	Crown destroyed							
Suggested Treatment: Boulder packing and plain shotcrete on the rock ledge on both sides of the staircase near and outside the entrance. Shotcreting the façade to increase strength, with provision of drainage holes. Extending the shotcrete along the hill slope up to the foot track to Khultabad. Existing drain situated on the up-slope side of the foot-track to be cleaned and lined.									
Cave 16	Cells on either sides of entrance approached from inside	Highly fractured & moderately weathered	Zone of rock fall	-	II to III				
	Right verandah of Kailash		Zone of rock fall	-	I		-	-	-
	Bridge between right verandah and 2nd deck of Pad Lanka	Already collapsed		-	-		-	-	-
	2nd deck of Pad Lanka		Zone of rock fall	-	I to II		-	-	-
	3rd deck of Pad Lanka								
	4th deck of Pad Lanka	Dilapidated condition		-	II to III		-	Color due to bats	WS & calc scales
	Overhang of Parikrama	Collapsed in some portions	Zone of rock fall at Places	-	II		-	-	-
Suggested Treatment: Reinforced shotcrete with rock bolts in the NW corner above the verandah having images of Ganga, Jamuna & Saraswati. Removal of loose blocks in the NE corner of the Parikrama. Rock bolting of loose blocks in the overhang of the Parikrama. (Vertical bolts). Removal of the half constructed pillars in Pad Lanka. Rock bolting of rock mass to the east of Pad Lanka (Horizontal bolts). Shotcreting of the crown of the verandah on the left of the entrance (on the front wall and approached from the inside. Pressure packing of the gap between the pillars and crown of first deck of Pad Lanka. Removal of the old and crumbling gunting surface on the hill slope on the southern side of the cave and shotcreting the surface. Repairing the gunited surface on the northern slope where necessary. Shotcreting of the excavated area to the east of the eastern cut face. Smoothing of the ground with a gradient towards south to drain the water. Treatment of the drain carrying water along the hill slope by lining of the channel and diversion of the channel down slope through a steel pipe to stop infiltration. - For caves 16 A, B, C: A) Surface shotcrete extending up to 5 m from the top till the base of the scarp. B) Providing a drain at the base of the scarp all along to divert the collected water to the nalla north of the cave C) Diverting flow towards the northern part of the nalla by filling up the depressions									

Cave 17	Left cell	Cracks of grade 4 & 5 in roof and pillars	Zone of rock fall	-	IV	Pillar made for support	-	Heavy water seepage
	Arch support in courtyard	Highly damaged due to cracks	Zone of de-slaking	-	III	-	-	-
Cave 18	Left cell	Crack at the base and roof	-	-	II to I	-	-	Water seepage
	Verandah left corner	Crack of grade 3 along crack in filling	-	-	II to I	-	-	WS with cal. encrustation
<u>Suggested Treatment:</u> Grouting of pillar left side in verandah, Encasing and repairing of pillar in left cell, Scrapping of rock surface and shotcrete up to retaining wall, Filling of two water tanks present above the cave, Existing drain to be repaired and taken to bed rock and provided with weep holes on upstream side.								
Cave 19	Verandah	Cracks of grade 4 & 5	Zone of rock fall	-	IV	Incomplete pillars	-	WS with stalactite
<u>Suggested Treatment:</u> Encasing of pillars in verandah and completing construction to support roof. Scrapping of existing gunited surface and shotcrete up to 10 meter from portal of cave, and repairing of rest of existing gunited surface. Nalla cut through crack in filled portion to be lined up to 20 meter upstream.								
Cave 20	Verandah	Crack of grade 3 in roof	-	-	-	-	-	Water seepage
<u>Suggested Treatment:</u> Shotcrete up to existing drain (up to 10 meter.), Improvement of drainage.								
Cave 21	Right cell in verandah	Crack of grade 3	Zone of rock fall	Pitting	III	-	Discoloration due to bats	Water seepage in right cell
<u>Suggested Treatment:</u> shotcrete up to existing drain, Relaying of existing drain cutting up to bedrock and providing weep hole for collecting water in soil surface. Wide gap in left wall in verandah to be filled or shotcreted.								
Cave 22	Left aisle in verandah	Crack of grade 3	-	Loss of sharpness	II to I	-	-	Water seepage
<u>Suggested Treatment:</u> shotcreting in northern part up to rock cut escarpment face (approx. 8m) and at base of escarpment, providing drainage and join it to existing drainage.								
Cave 23	Cell extreme left	Pillars with cracks of grade 4	Zone of de-slaking	-	IV	-	-	Water seepage
<u>Suggested Treatment:</u> shotcreting up to existing drain on top, Removal of stray boulders and removal of plants.								
Cave 24	Verandah	Crack of grade 4 & 5 in roof	-	-	III	-	-	Heavy water seepage
<u>Suggested Treatment:</u> Extending shotcrete up to 3 meter from facade of cave 24A.								
Cave 25	Verandah	Crack of grade 3 in roof	-	-	II to I	-	Discoloration	Water seepage
<u>Suggested Treatment:</u> Existing pillars to be repaired, shotcreting up to 5 meter from cave portal.								
Cave 26	Verandah	Cracks of grade 2 & 3	-	-	II to I	-	-	-
<u>Suggested Treatment:</u> Filling of cracks inside the cave. Shotcreting up to 5 meter upstream. Epoxy grouting								

Cave 27	Verandah	Cracks of grade 2 & 3	-	-	II to I	-	-
Cave 28	Verandah	Cracks of grade 1 & 2 in roof and walls are	-	-	IV	-	-
Suggested Treatment: Epoxy / polymer coating for weathered rock.							
Cave 29	Verandah	Crack of grade 5 in roof	-	-	II to I	-	Water seepage
	Left unfinished cell	Cracks of grade 4 & 5	Zone of rock fall	-	III	-	Heavy Water
Suggested Suggested Treatment: Treatment for distressed pillars in central hall. Repairing and filling of cracks in left cell. Shotcreting 5 meter up to retaining wall and improving drainage.							
Cave 30	Entrance structure	Cracks of grade 4 & 5	-	Loss of sharpness	III	-	Water seepage
	Verandah/Hall	Pillars weathered at base	-	-	IV	Some pillars repaired	Water seepage
Suggested Treatment: Shotcreting of northern (backside) wall and providing drain on top. Shotcreting and crack filling in left front side. Epoxy / polymer coating for weathered rock and cracks. Removal of loose dislodged boulders / rock blocks on backside hilltop of cave. Strengthening of damaged pillars. Management of accumulated water in courtyard.							
Cave 31	Verandah	Cracks of grade 4 & 5	-	-	II to I	Crack repaired	Water seepage
Cave 32	Left cell in courtyard	Crack of grade 4 & 5	-	Sculpture damaged	II to I	Crack repaired	Water seepage
	Right cell in courtyard near main electric switch board	Crack of grade 5	-	-	II to I	-	WS with cal. encrustation
Suggested Treatment: Removing of existing gunited portion and relaying of shotcrete up to retaining wall and providing drain up to bedrock. Diversion of surface water towards southern side drain of cave 32B. Filling of cavity on right side facade.							
Cave 32B	Verandah	Cracks of grade 4 & 5 in crown portion	-	-	II to I	-	Water seepage
Suggested Treatment: Cleaning and lining of existing drainage channel. Removal of existing gunited surface and relaying of shotcrete further ahead of retaining wall and providing drainage leading to right side. Epoxy / polymer coating for weathered rock and cracks. Drain behind the retaining wall is to be deepened up to bedrock and widen. Provision of weep holes.							
Cave 33	Right cell in courtyard	Crack of grade 4 & 5	-	-	III	Wall damaged	WS with formation of stalactite
Cave 34	Verandah	Cracks of grade 5 in left corner of verandah	-	-	II to I	-	Water seepage
Suggested Treatment: Removing of existing gunited surface and relaying by shotcrete up to retaining wall. Providing drain (deep channel) with weep holes (up slope side) up to bedrock. Improving existing water drains (two) from hill slopes by lining or making impervious and draining the water ahead of cave 34. Removal of rolled boulders on top of cave 33.							

The background of the page is a photograph of the interior of an Ellora cave. It features a large, white, seated Buddha statue in the center, with a smaller, similarly seated figure to its left. The cave walls are dark and textured, and the lighting is somewhat dim, highlighting the statues.

C H A P T E R V I I I

ENVIRONMENTAL STUDIES OF ELLORA CAVES

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CHAPTER-VIII

ENVIRONMENTAL STUDIES OF ELLORA CAVES

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VIII. ENVIRONMENTAL STUDIES OF ELLORA CAVES

STATUS OF EXISTING ENVIRONMENT

Environmental studies were carried out with the objective to assess the status of existing environment and to suggest mitigation measures for the negative impacts on the monuments. Parameters covered under the present studies include:- micrometeorology, ambient air quality, water quality, noise levels, ambient temperature and humidity inside the caves, impact of developmental activities etc.. Data was collected and generated for the period from January to December 1999.

MICROMETEOROLOGY

Atmospheric conditions determine the behavior of air pollutants after they leave the source and reach the receiving objects such as human beings, animals, plants and cave sculptures as in the present case. The effect of pollution also depends on the atmospheric conditions. Therefore, study of minute variation in atmospheric conditions around the caves is of utmost importance. To achieve this, data on meteorological parameters such as *temperature, relative humidity, wind speed and wind direction and rainfall* was generated by installing maximum and minimum thermometer, maximum and minimum humidity recorder and rain gauge and by observing the seasonal variation in wind direction.

WIND SPEED AND WIND DIRECTION

Two basic and primary meteorological parameters such as speed and direction of wind control the dispersion and dilution of the pollutants. Apart

from other secondary factors, wind speed directly determines the rate of dilution and transport of air pollutants, whereas wind direction directly determines the direction of transport of air pollutants.

The prevalent wind direction was observed from January to December 1999 and is tabulated in Table VIII -1. Prevalent wind direction during the months of January to March was northerly and northwesterly. During the months of April to September the wind direction was westerly and during the month of October the wind direction was bi-modal while the prevalent directions were easterly and northeasterly. During the months of November and December the prevalent wind directions were northerly and north- westerly.

AMBIENT TEMPERATURE

The ambient temperature has several effects on various parameters of the environment, air pollution in particular. Though, it is known that the chemical reaction rate in atmosphere is influenced by ambient temperature, yet it is difficult to isolate the effects of temperature from those of solar radiation and humidity.

Ambient temperature was recorded at Ellora during the year 1999. The minimum and maximum temperatures are tabulated in Table VIII -1. During the winter months the mercury touched a low of 10⁰ C whereas it had reached a high of 44.1°C during summer months.

PRECIPITATION

During the year 1999 the area received only 512 mm of rainfall during the monsoon season, which is much lower than the average annual rainfall.

HUMIDITY

At Ellora, humidity was measured round the year and minimum and maximum humidity for each month are tabulated in Table VIII -1. During winter it varied from 24% to 89%, during summer its range was between 13% and 99%, while during monsoon the range was from 31.4% to 99%.

FLORA AND FAUNA

FLORA

The flora of the area represents tropical deciduous scrub forests. This is a degradation stage of dry deciduous forest and is continued to areas with poor soil and steep slopes. The species exhibit various stages of transition from tree forests to scrub forests. The species that are found scattered are khair (*Acacia catechu*), hiwar (*Acacia leucophloea*), dhawada (*Anogeissus latifolia*), mohi (*Lannea coromandelica*), salai (*Boswellia serrata*), bor (*Zizyphus mauritiana*), balas (*Butea monosperma*), tendu (*Diospyros malanoxylon*), apta (*Bauhinia racemosa*), semal (*Solmalia molbarica*), bondara (*Lagerstroemia parviflora*), neem (*Azadirachta indica*), pipri (*Ficus religiosa*) etc.

The scrubs and other undergrowth which cover most of the area consist of henkal (*Gymnosporia montana*), ghaneri or raimoni (*Lantana camara*), amti (*Emblia robusta*), parhenkal (*Floerkea ramantohi*), karvand (*Carissa carandas*), sabar (*Euphorbia* species), medsing (*Dolichandrone jalcata*), lokhani (*Ixora parviflora*) and padhri (*Gardenia turgida*).

Common grasses found in the area are kusali

(*Heteropogon contortus*), Gondala (*Andropogon pumilus*), sheda (*Ischaemum laxum*), marvel (*Dicanthium annulatum*), pavaya (*Schinus nervosum*) and rerely rosha (*Cymbopogon martini*).

FAUNA

The fauna present in the area include panther (*Panthera pardus*), chital (*Axis axis*), gazelle (*Chinkara gazella benetti*), wild boar (*Sus cristatus*), jackal (*Canis aureus*), monkey (*Presbytis entellus*), sasa/hare (*Lepus ruficaudatus*) and squirrel (*Funambulus palmarum*).

Pea fowl, mor/peacock (*Pavo cristatus*) and jungli murghi (*Gallus sonnerati*) are among the bird species commonly seen in the area.

Non poisonous snakes found in the area are *Typhlops bramineus*, *Uropeltis*, *Eryx conicus*, *Lycodon aulica*, *Python molurus*, *Ptyas mucosus*, *Natrix piscator*, *Natrix stoliczkae*, *Dryophis nasutus* and *Ahaetulla grandoculis*.

Poisonous snakes found in the area are Elapidae (*Naja naja*), *Bungarus caeruleus*, *Vipera russelli*, *Echis carinatus* and *Trimorphodon* species.

AMBIENT AIR QUALITY

Air monitoring was carried out to assess the air quality of Ellora caves area and its impact on monuments, if any, and to suggest appropriate control measures. Based on the observation and preliminary field survey, three sampling sites were selected. At these locations *respirable dust samplers* were installed and air samples were collected for Respirable Particulate Matter (RPM), Suspended Particulate Matter (SPM), sulphur dioxide (SO₂) and nitrogen dioxide (NO₂) content determinations. 210 samples for each parameter were collected, spread over a period of one year and measurements were made on a twenty four hourly basis at cave no. 16 (above booking office),



cave no. 15 (near entrance more than 10 ft height), cave no. 32 (above cave no. 31) and cave no. 10 & 20 (in the month of August)

Results of the analysis (Table VIII - 2) reveal that:-

- i) **Cave no. 16** - Higher values of Respirable Particulate Matter and Suspended Particulate Matter were recorded during the months of February, March and April. SPM levels ranged between 101.78 mgm/m³ and 180.84 mgm/m³, which are above the permissible limits of 100 mgm/m³. RPM levels varied from 76.66 to 118.89 mgm/m³ and these two values are above the permissible limit of 75mgm/m³ and in the month of November. SPM levels were 124.31 mgm/m³ and these are above the permissible limit. Gaseous pollutants (SO₂ & NO₂) are well within the permissible limits of 30 mgm/m³.
- ii) **Cave no. 15** – The results reveal that the SPM and RPM values are above the permissible limits of 100 & 75 mgm/m³ in the months of March and April i.e. 210.64 and 200.08 mgm/m³ and 116.01 and 102.99 mgm/m³ respectively. The gaseous contents are well within the permissible limit during all the months.
- iii) **Cave no. 32** –Analytical results show that the SPM and RPM values are less here than at cave no. 16 and 15. Though they are all above the permissible limits of 100 and 75 mgm/m³ i.e. SPM values are 130.77 and 172.53 mgm/m³ and RPM values are 92.47 and 80.41 mgm/m³ during the months of March and April respectively,

- iv) **Cave nos. 10 & 20** – Comparative study was carried out at caves 10 and 20 during the month of August. The values of all the four parameters are less than those at cave no. 32, 16 & 15.

WATER QUALITY

To know the water quality of Ellora caves area, 6 numbers of stream water samples, 13 numbers of storage tank water samples and 7 numbers of seepage water samples from caves were collected, each for major oxides and toxic elements determination and for carrying out bacteriological test. In the Ellora caves area there are three main streams a) above the cave no. 5, b) north of cave 16 and c) above cave no. 28. These are ephemeral streams flowing for 6 to 8 months in a year and are the main source of water in the area. Cave nos. 1, 3, 10, 11, 12, 13, 15, 16, 17, 25, 27, 29 and 34 have underground water storage tanks in which rain water flowing from the scarp face is collected and stored. In addition to the above, water supply scheme from Khultabad supplies to Ellora caves. But the water stored in the water storage tanks of cave 11 and 15 is being used for drinking purpose after treating it with bleaching powder/lime.

The chemical analytical results are as given in Table VIII-3 and VIII - 4

To ascertain the suitability of water for drinking purposes, 7 nos. of water samples were collected for bacteriological tests and submitted to the Maharashtra State Public Health Services Laboratory at Aurangabad. The analytical results as given in Table VIII - 4 show that water from storage tanks in cave nos.11, 12, 15 and 29 and streams near cave 5, 16 and 29 is not potable. It contain *coliforms* > 16 per 100 ml of water and the thermotolerant bacteria ranges between 3 and



16 per 100ml of water. The prescribed limits for the total *coliforms* as per IS 10500 (1983) are:

- a) Throughout any part of the year 95% of samples should not contain any *coliforms* in 100ml and
- b) No sample should contain > 10 *coliform* organism per 100 ml water. Storage tank of cave no. 11 shows comparatively high value of thermotolerant bacteria.

Chemical analysis of 25 samples for 23 parameters collected during two seasons i.e. winter and summer and seepage water in the rainy season, shows that the major mineral constituents and toxic metals are well within the permissible limits as assessed against IS 2296 (Class 'A' water) (Table VIII - 3). Storage tank water of cave 34 during winter and summer shows pH values of 5.90 and 3.60 which indicate that it is acidic in nature.

AMBIENT NOISE LEVELS

To assess the noise levels inside the Ellora caves and outside the caves, noise levels were monitored at various locations during the months of March and April 1999. The plates VIII-1, 2 & 3 show the range of general noise level, frequent peaks and rare peaks measured in selected caves during the above period.

To know the average noise level during peak hours, noise levels were recorded using data logger at an interval of 0.125 seconds in selected caves viz. caves 1, 2, 6, 10, 12, 16, 32 at the parking and near staff canteen. The log values are shown in Plates VIII -1, 2 & 3. These plates clearly show that caves which are closed from all sides i.e. cave nos. 2, 10, 8, 16 suffer the most from noise pollution as compared to the caves which are open i.e. 1, 6,

12 and 32. The noise level data at the selected locations/sites are summarized as follows:

- i) Frequency curve for the cave 1 shows that the background values inside the cave are 40 dBA and when visitors are inside the cave, frequent peaks are of 60 dBA with rare peaks reaching 70 dBA levels.
- ii) Noise levels in cave no. 2 are comparatively high. Here the frequency peaks are above 60 dBA with rare peaks crossing even 90 dBA levels.
- iii) In cave no. 6 though rare peaks touch 65dBA level the average levels are lower.
- iv) In the lower deck of cave 12 frequent peaks touch 70 dBA with rare peaks touching even 80 dBA levels. Average levels however remain at 55 to 65 dBA.
- v) In cave no. 10 the average levels are of 70 dBA and rare peaks cross 120 dBA.
- vi) In cave no.16 the average levels are 70 dBA and rare peaks are upto 90 dBA. The frequent peaks are of 75 dBA.
- vii) In cave no. 32 the rare peaks touch 80 dBA and frequent peaks are of about 55 dBA levels.
- viii) The average noise level in the parking area is 60 dBA, frequent peaks are above 65dBA and rare peaks touch 90 dBA levels.
- ix) Near staff canteen frequent peaks are of 75 dBA and rare peaks cross 80 dBA levels, though the background values are of about 55 dBA.

Based on the measurements carried out and physical observations, following inferences are made:

Plate : VIII-1

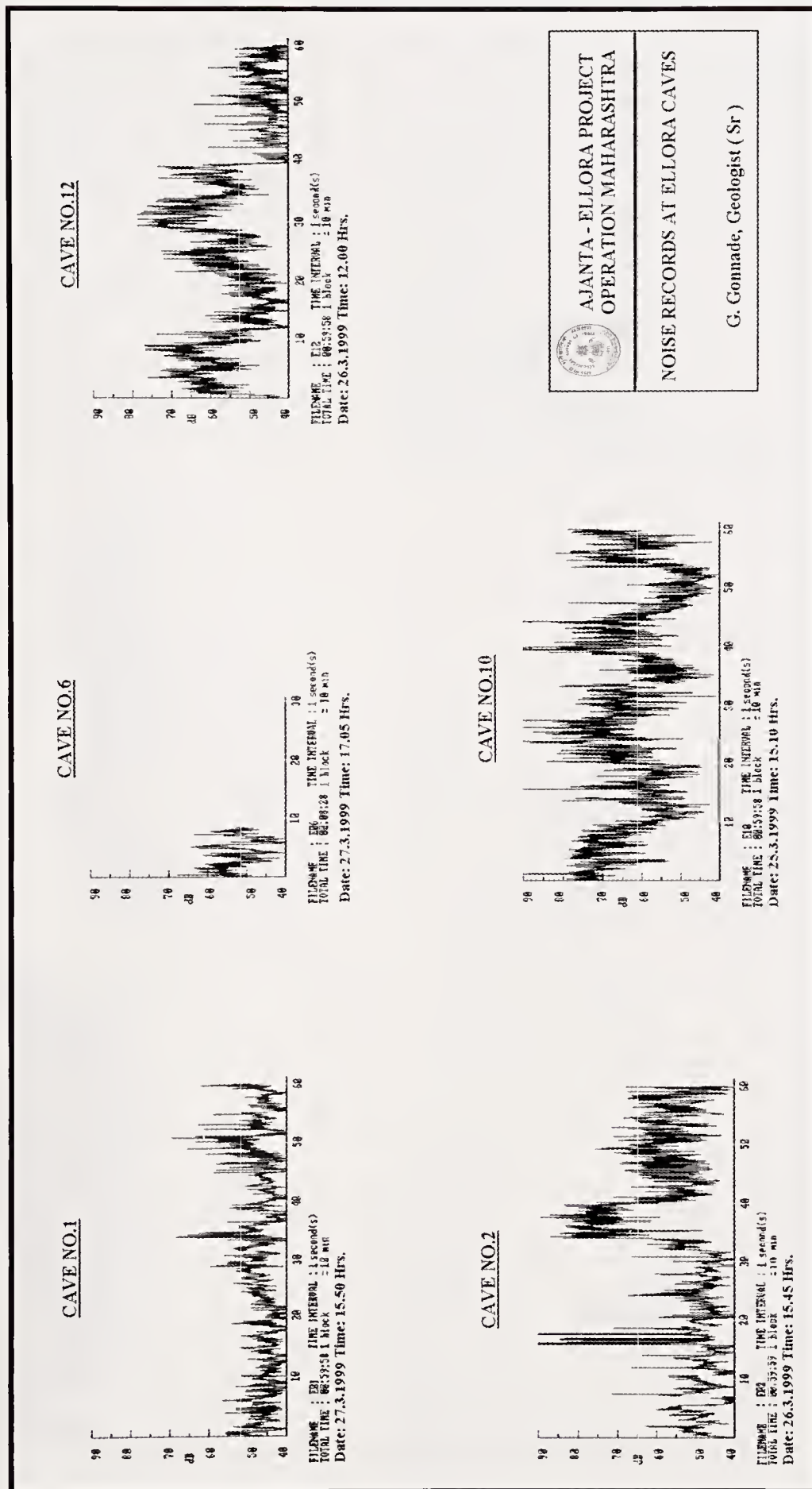
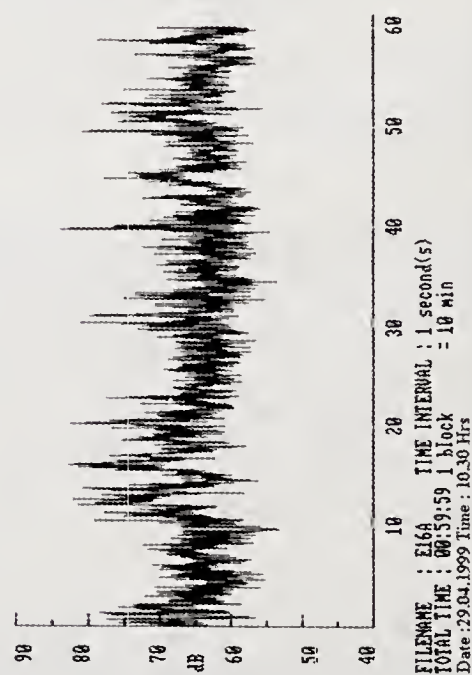


Plate : VIII-2

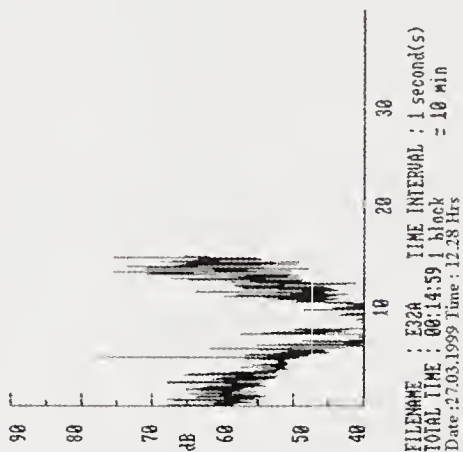
CAVE NO. 10



CAVE NO. 16



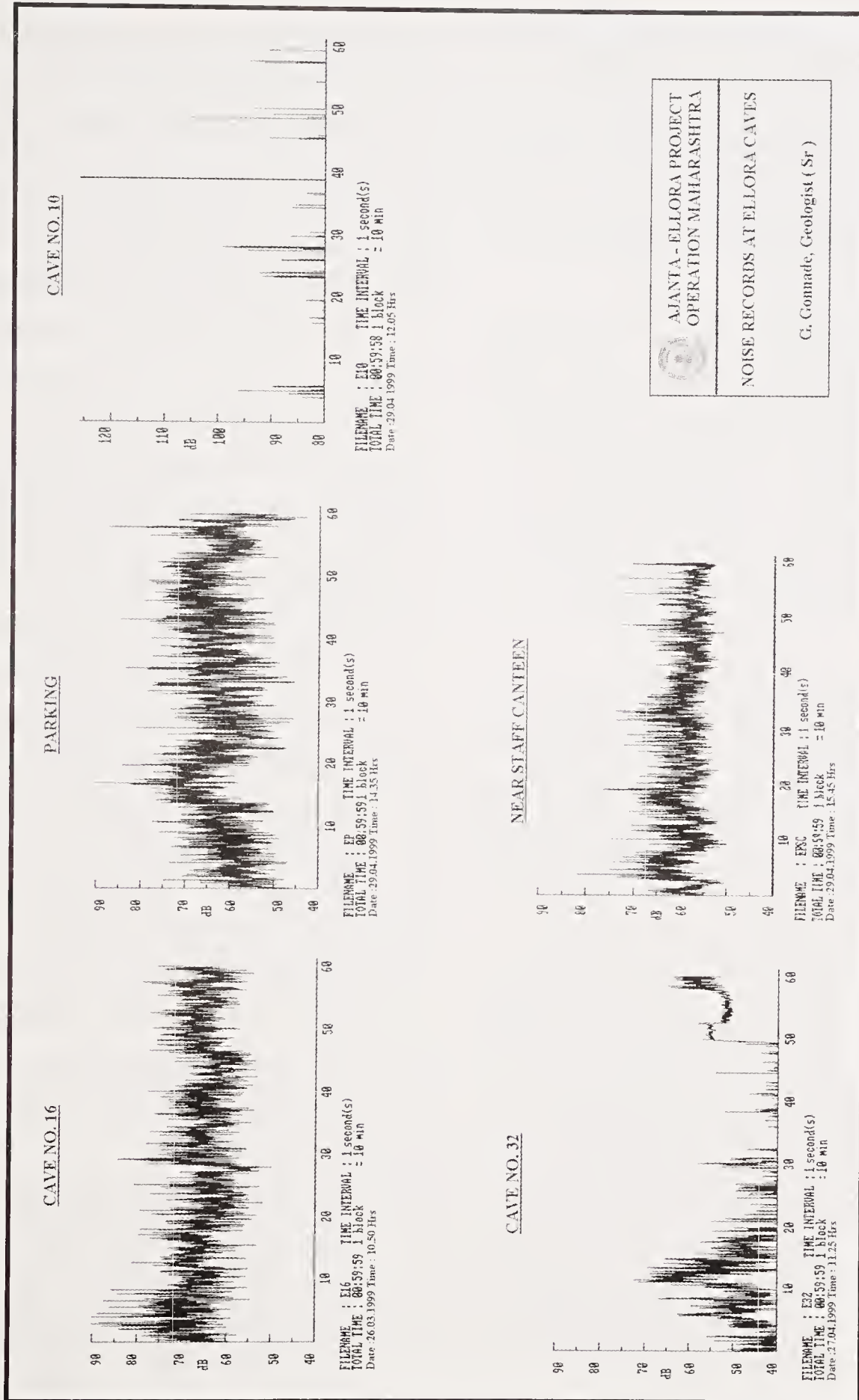
CAVE NO. 32

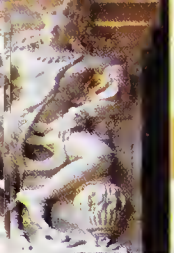


AJANTA - ELLORA PROJECT
 OPERATION MAHARASHTRA

NOISE RECORDS AT ELLORA CAVES

G. Gonnade, Geologist (Sr)





- a. IS 4954 – 1968 does not specify the permissible limits for cave areas.
- b. Limits for the silence zone i.e. 50 dBA may be considered as safe limit.

TEMPERATURE AND HUMIDITY IN CAVES

As part of environment monitoring program, temperature and humidity were recorded in all the 34 caves at Ellora. 17 caves were selected for the comparative study considering their size, shape, location, elevation, type and paintings. Measurements were taken for 2 days in a week for 2 weeks (between 0940 hrs – 1345 hrs^{hrs}) during each month and average was calculated for each month.

The selected caves include cave nos. 1, 2, 5, 6, 10, 12, 14, 16, 17, 19, 19 B, 21, 25, 29, 30, 32 (upper deck) and 34. Plate VIII - 4 to 20 gives the complete range and variation in temperature and humidity with their corresponding values outside the caves.

- i) In cave 1 the average temperature and humidity at 9.40 hrs. inside the cave varied from 16 °C to 32.4°C and 25% to 74% respectively. In the cell, temperature varied from 17°C to 31.8 °C and humidity from 23% to 76%. Outside temperature varied from 15°C to 32.9°C and humidity from 25% to 73%. Thus the annual average variation is 16.4°C and 49% in temperature and humidity respectively inside the cave and 14.8°C and 53% in the cell.
- ii) In the cave 2 at 9.50 hrs. the temperature and humidity varied from 22.5°C to 32.1°C

and 31% to 76% respectively. In the antechamber it varied from 21.5 °C to 31.5 °C and 36% to 81% respectively, whereas outside the caves the corresponding values are 15 °C to 32.9°C and 25% to 73%. Thus inside the caves the variation in temperature and humidity is 9.6°C and 45% respectively and in the antechamber it is 10°C and 45%.

- iii) In cave 5 at 10 hrs. temperature inside the cave varied from 19°C to 31.1°C and humidity varied between 24% and 73%. In the antechamber temperature varied from 19.5°C to 38.8°C and humidity from 26% to 81%. Outside temperature and humidity fluctuated between 15°C to 32.9°C and 25% to 73% respectively, thus having a variation of 12.9°C and 49% in the inside temperature and humidity over a period of one year.
- iv) Average daytime monthly temperature and humidity inside cave 6 in antechamber and outside at 10.20 a.m., varied from 19°C to 31.5°C and 28% to 73%, 19°C to 31.5°C and 26% to 81% and 15°C to 32.9°C and 25% to 73% respectively. The difference in temperature and humidity inside the cave is about 12.5 °C and 45% respectively, over a period of one year.
- v) Outside and inside, average temperature and humidity in cave 10 at 11.00 hrs. varied from 19°C to 33.2°C and 24% to 71% and 20°C to 34.5°C and 26% to 71% respectively. The annual difference in temperature and humidity inside the cave was 14.5°C and 45% respectively.



- vi) In the upper decks of caves 12 at 11.40 hrs. the temperature and humidity inside, outside and in antechamber varied from 21°C to 33.5°C and 29% to 69%, 24.0°C to 33.5°C and 32% to 69% and 21°C to 33.5°C and 40% to 77% respectively, thus having annual difference inside the cave in temperature and humidity of 12.5°C and 40%.
- vii) Temperature and humidity in cave no. 14 at 12.30 hrs. outside, inside and in antechamber varied from 22°C to 34.5°C and 34% to 67%, 23°C to 34.8°C and 32% to 69% and 22.5°C to 34.5°C and 26% to 69% respectively. The annual difference in temperature and humidity inside the cave was 11.8°C and 37% respectively.
- viii) In cave 16 the average temperature and humidity at 13.15 hrs. varied from 22°C to 35.6°C and 30% to 66% and 22°C to 35.6°C and 29% to 69.1% outside and inside respectively. The average annual fluctuation in the temperature and humidity inside the cave were 13.6°C and 40% respectively.
- ix) Monthly average of temperature and humidity in the cave 17 at 9.00 hrs. outside, inside and in the antechamber varied from 17°C to 32.7°C and 36% to 73%, 18°C to 31.1°C and 35% to 69% and 19°C to 31.1°C and 33% to 76%. Thus annual variation in temperature and humidity inside the cave was 13.1°C and 34% respectively.
- x) Temperature and humidity variation recorded at 9.30 hrs. outside, inside and in antechamber of cave 19 is 17°C to 32.7°C and 36% to 73%, 18.5°C to 31.3°C and 35% to 59% and 20°C to 31.3°C and 35% to 73% respectively. Average fluctuation in temperature and humidity inside the cave was 12.8°C and 24% respectively.
- xi) In cave 19 B during daytime at 09.45 hrs. outside and inside temperature and humidity varied from 20°C to 32.25°C and 31% to 68% and 20°C to 31.6°C and 33% to 69% respectively. Thus the variation inside the cave over a period of one year, in temperature and humidity was 11.6°C and 36% respectively.
- xii) During daytime at 10.15 hrs. in cave 21, the variation in temperature and humidity outside, inside and in antechamber was 20°C to 32.25°C and 31% to 68%, 20°C to 32°C and 31% to 68% and 20°C to 32°C and 32% to 77%. Average annual fluctuation in temperature and humidity inside the cave was 12°C and 37% respectively.
- xiii) In the cave 25 at 11.15 hrs., outside, inside and in antechamber, the temperature and humidity varied from 20°C to 32.8°C and 31% to 66%, 23°C to 32.6°C and 30% to 66% and 24°C to 32.1°C and 27% to 76%. Thus the average annual difference in the temperature and humidity recorded inside the cave was 9.6°C. and 36% respectively.
- xiv) The monthly average of temperature and humidity in the cave 29 at 12:00 hrs. outside, inside and in antechamber varied

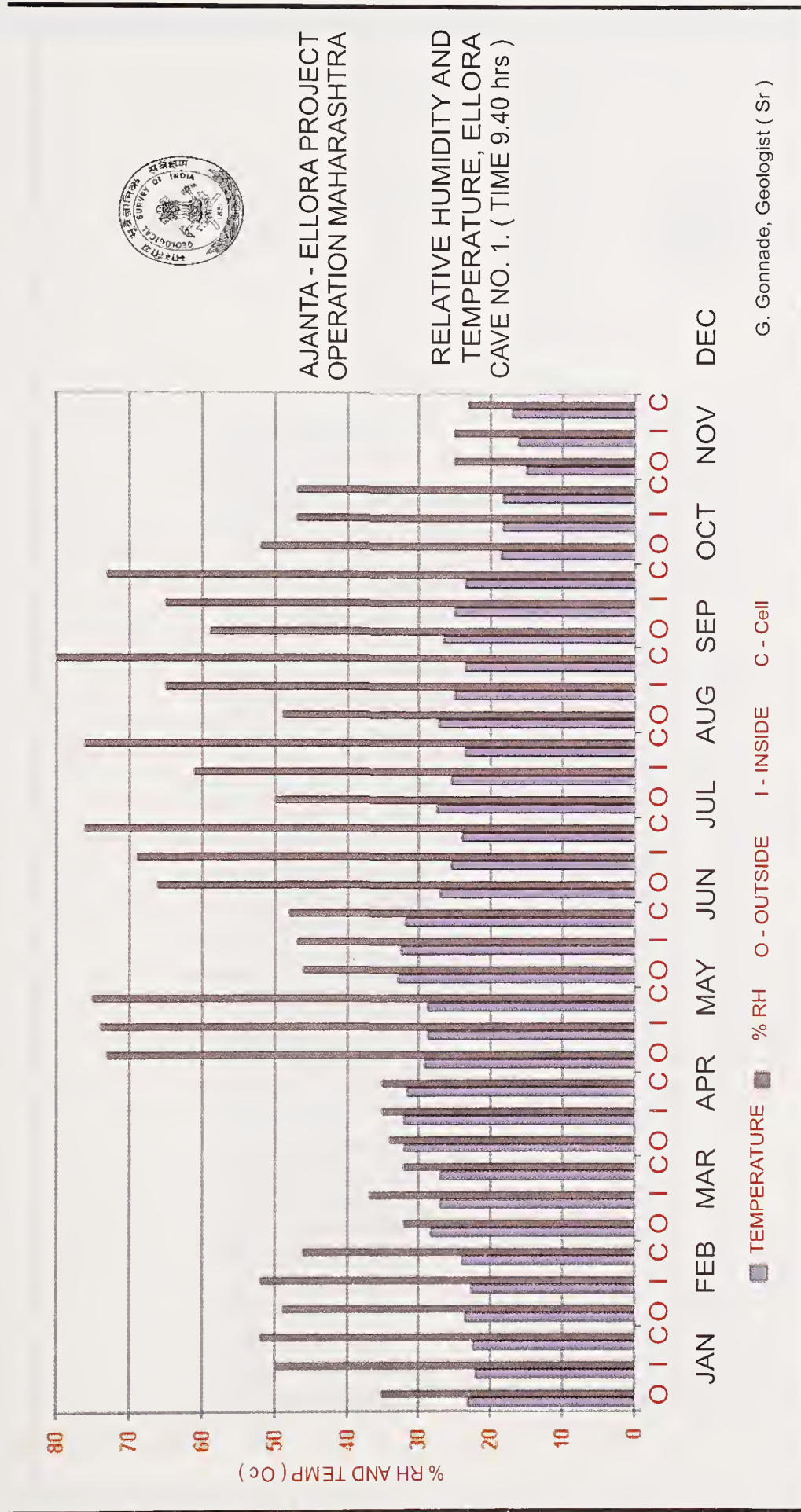


from 20°C to 32.8°C and 31% to 66%, 21°C to 33.3°C and 30% to 62% and 20.5°C to 33.2°C and 30% to 69%. The annual average difference of the temperature and humidity inside the cave over the period of one year was 12.3° C and 32% respectively.

- xv) In cave 30 at 12.15 hrs., the outside and inside temperature and humidity varied from 25.5°C to 35.7°C and 23% to 63% and 23°C to 35.4°C and 22% to 69% respectively. Average fluctuation in temperature and humidity inside the cave was 12.4 °C and 47% over a period of one year.
- xvi) Temperature and humidity outside, inside and in antechamber, in the top deck of cave 32 at 13.15 hrs. varied from 23.5°C to 34.8°C and 23% to 66%, 23°C to 33.5°C and 26% to 69% and 22.5°C to 33.3°C and 25% to 69% respectively. The change in average temperature and humidity inside the cave was 10.5 °C and 43% respectively over a period of one year.
- xvii) The monthly average temperature and humidity during the daytime in cave 34 at 13.30 hrs. outside, inside and in antechamber varied from 23.5°C to 34.8°C and 23% to 69%, 23.5°C to 34.2°C and 23% to 69% and 24°C to 34°C and 23% to 77% respectively. The fluctuation in the temperature and humidity inside the cave was 10.7°C and 46% respectively over a period of one year.

Study of temperature and humidity data reveals that: -

- i) Inside and within the antechamber, temperature in most of the caves is always lower than the outside, except on rainy days when reversals take place in the less ventilated type of caves.
- ii) Caves 1, 2, 5, & 6 are facing toward northwesterly direction but cave no.2 is closed from all the sides and cave nos. 1, 5 & 6 are open from front. Temperature and relative humidity fluctuations in open caves are more pronounced as compared to cave closed from front (cave no. 2).
- iii) The annual average difference of the temperature and humidity in cave no. 10, 21, 29, 32 are more or less the same.
- iv) In the antechamber and Central hall of cave 12 and outside the cave, the humidity and temperature are more or less same.
- v) The difference between fluctuation in temperature and humidity inside the temple of cave nos. 16 & 30 is 1.2°C and 7% respectively. Fluctuations in these parameters in cave 16 are more pronounced than in cave 30.
- vi) Relative humidity variation inside the antechamber of most of the caves is more pronounced as compared to that outside the antechamber.



VIII - 9a

**AJANTA - ELLORA PROJECT
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**RELATIVE HUMIDITY AND
TEMPERATURE, ELLORA
CAVE NO. 2. (TIME 9.50 hrs)**

Month	Temperature (°C)	%RH	A-Ant. Chamber
JAN	25	75	80
FEB	28	78	82
MAR	30	80	85
APR	32	82	88
MAY	35	85	90
JUN	38	88	92
JUL	40	90	95
AUG	42	92	98
SEP	45	95	100
OCT	48	98	100
NOV	50	100	100
DEC	52	100	100

Plate : VIII-6

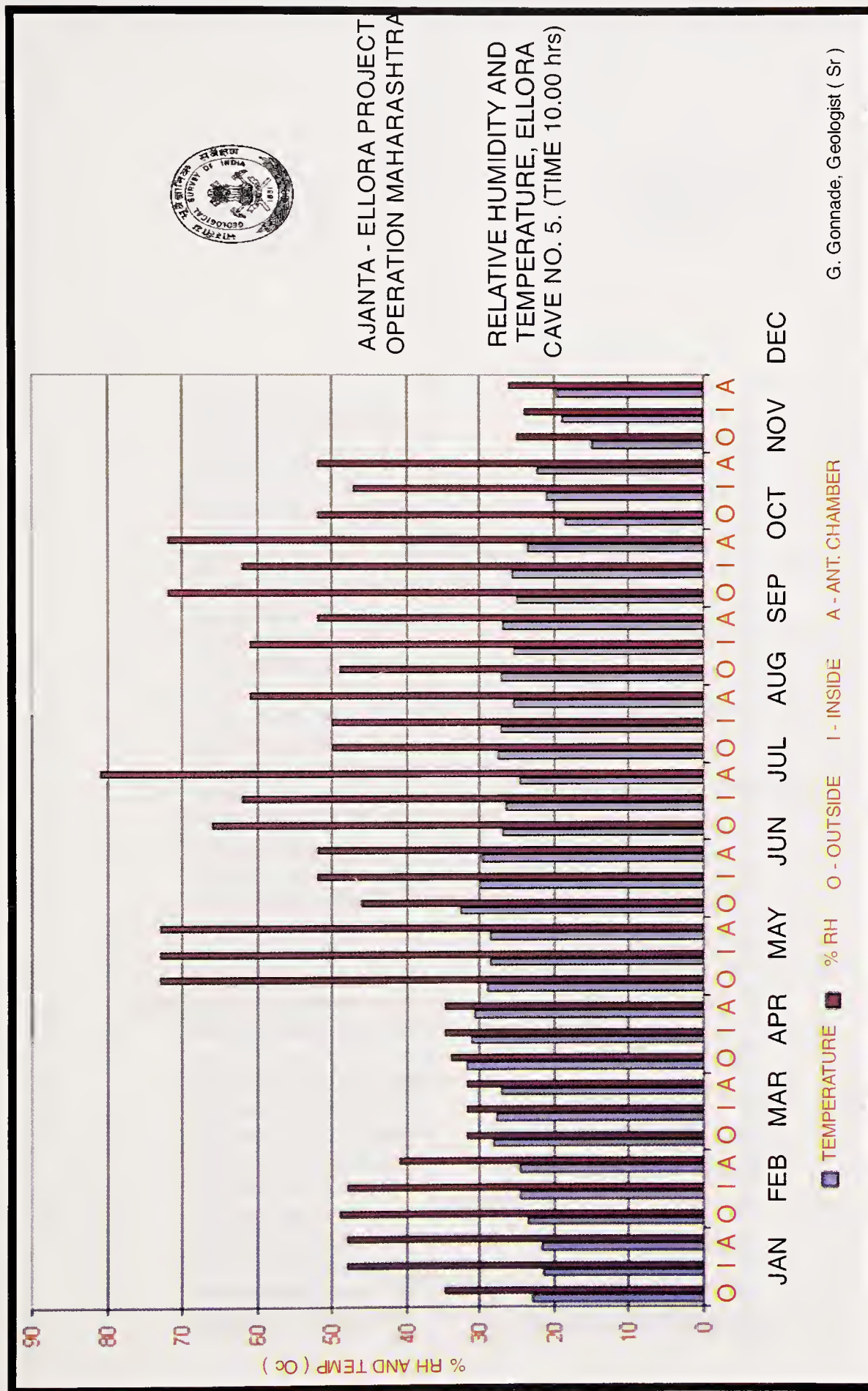


Plate : VIII-7

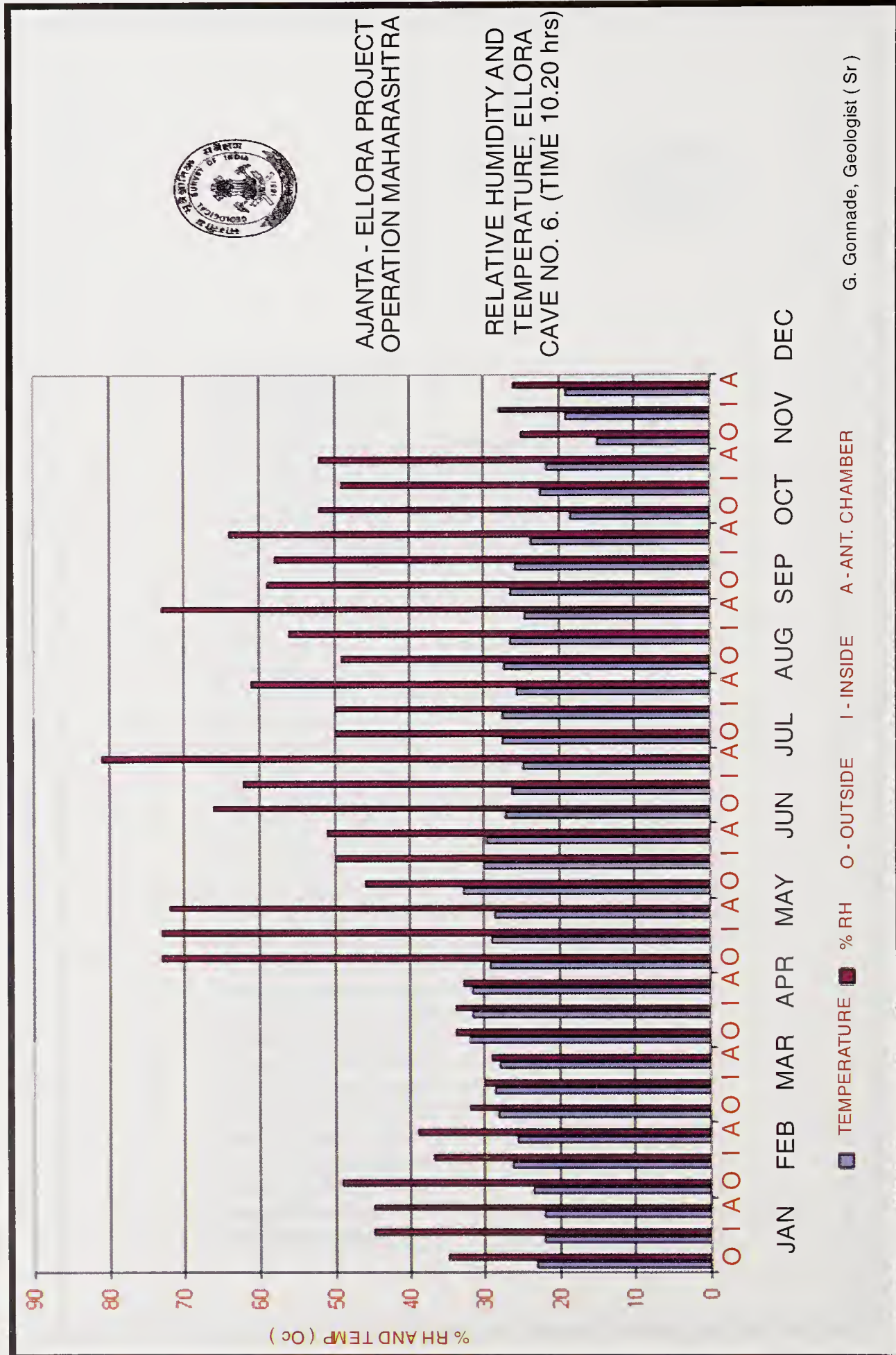


Plate : VIII-8

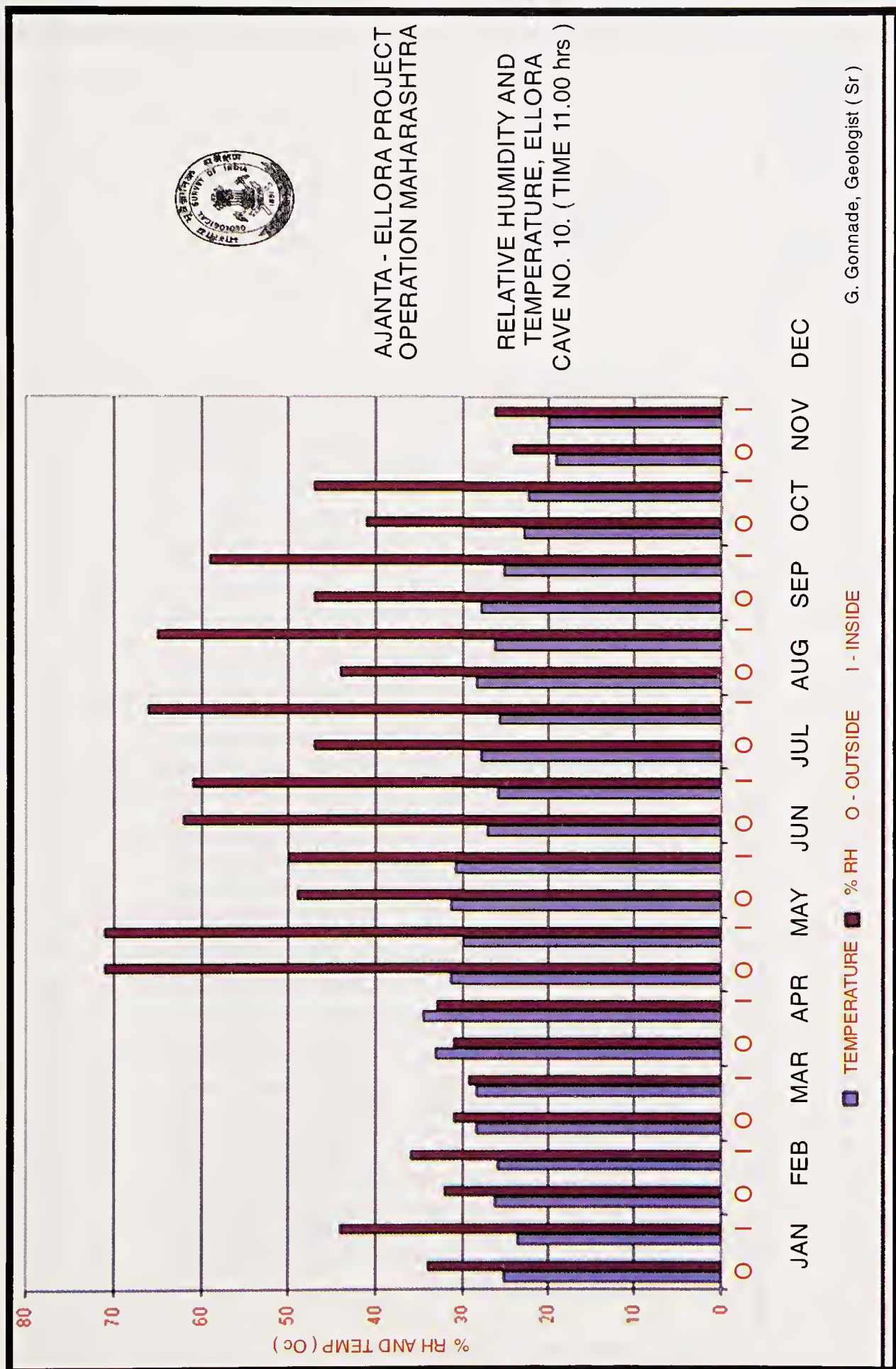




Plate : VIII-9

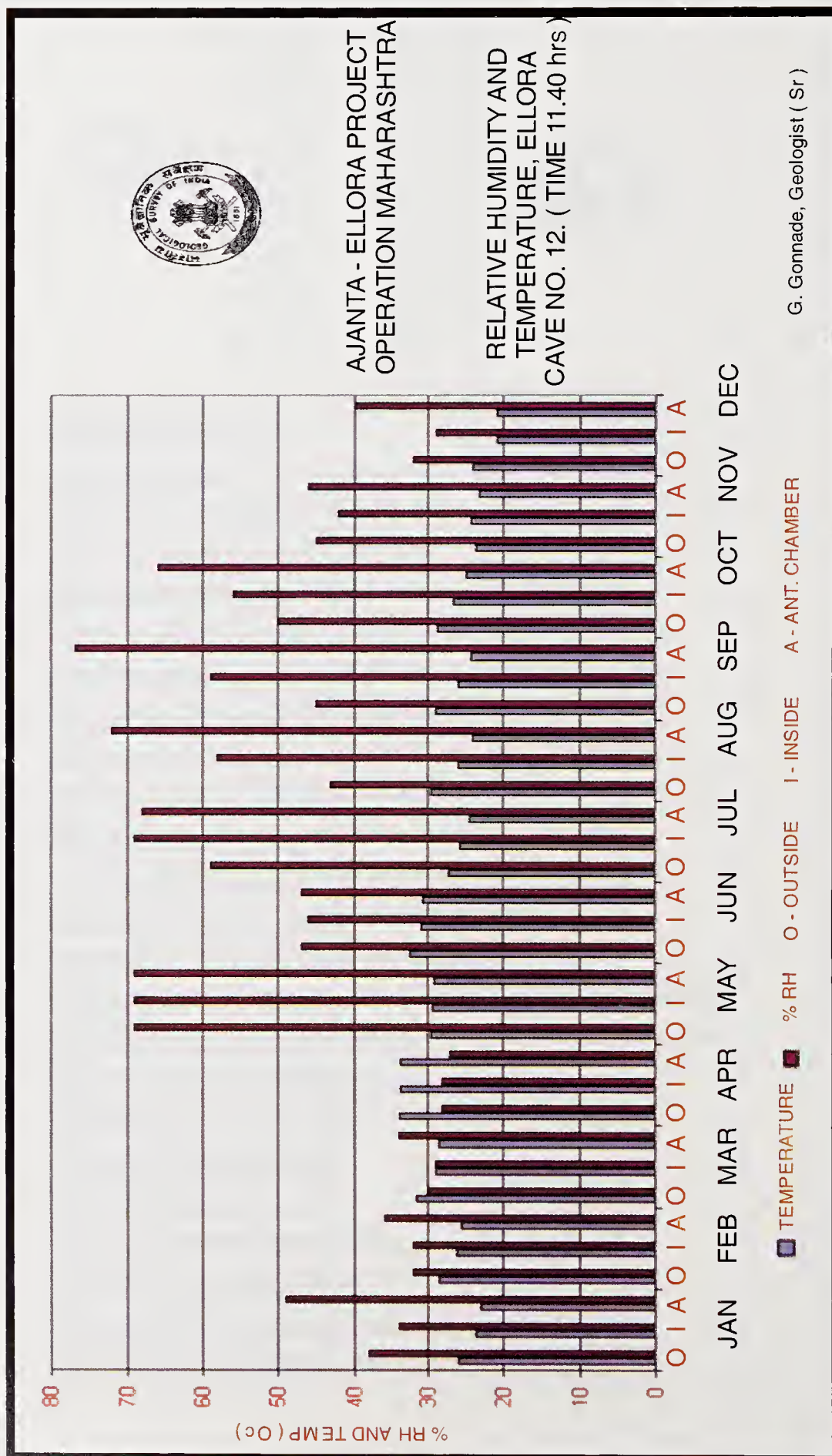


Plate : VIII-10

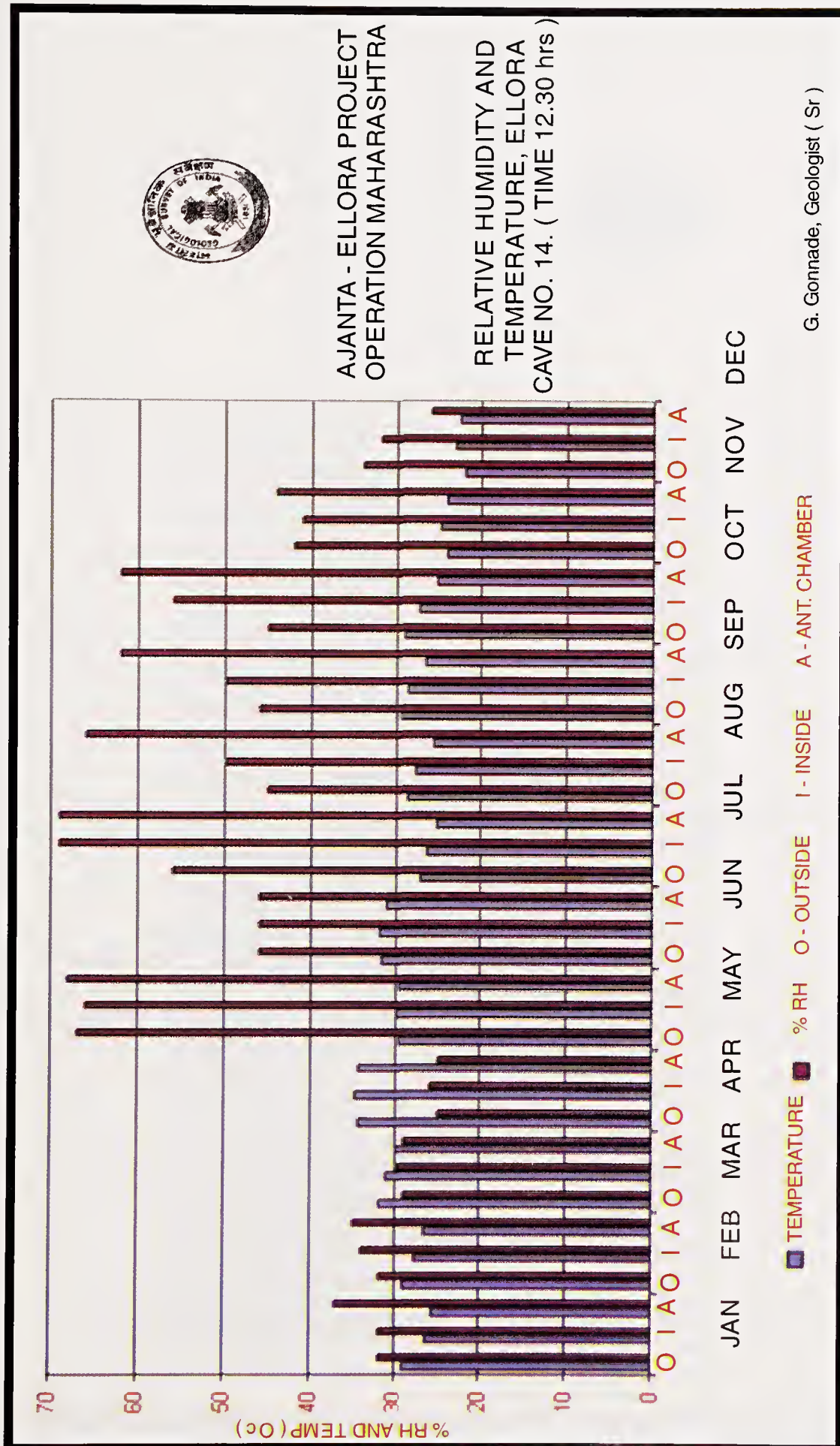
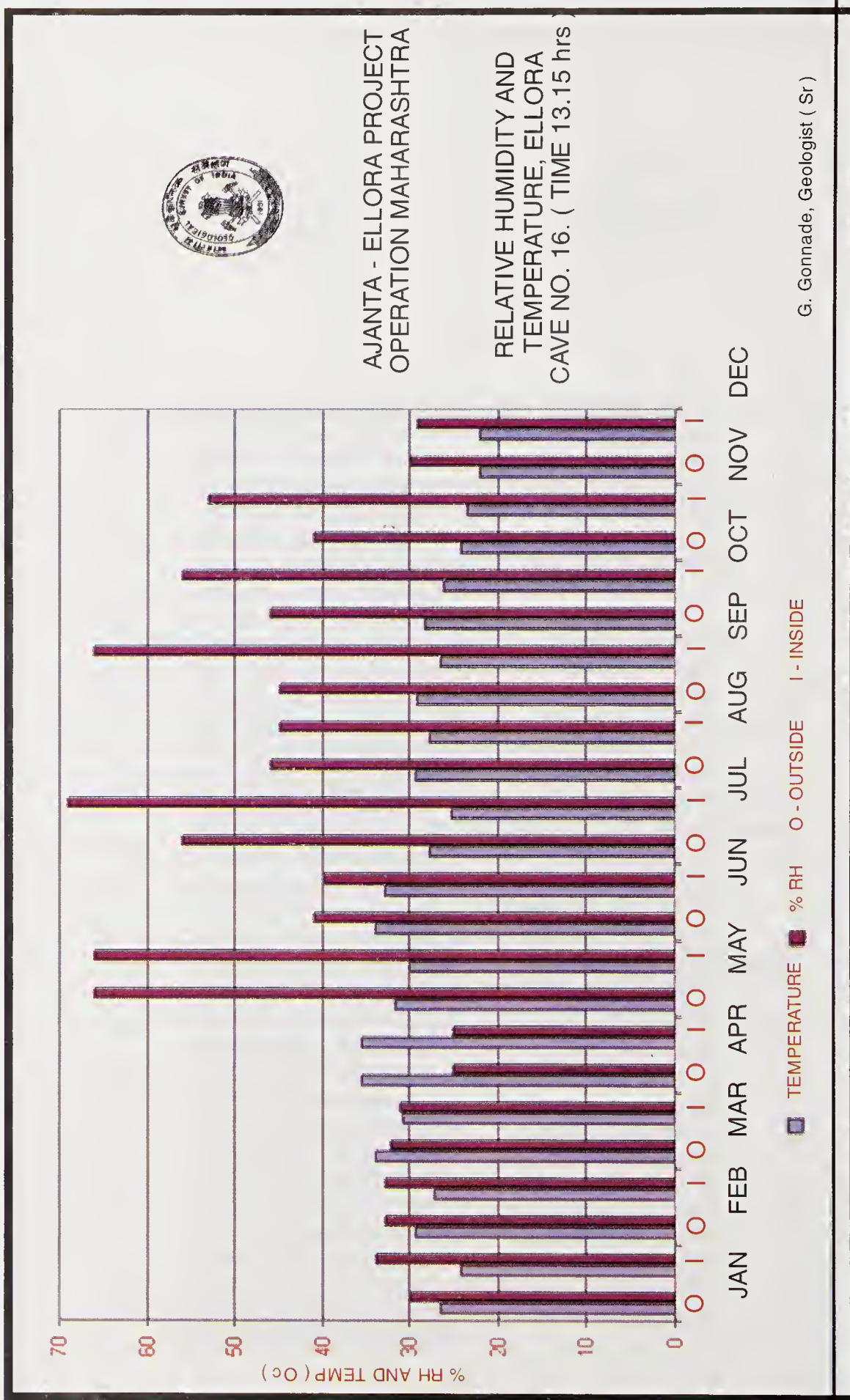


Plate : VIII-11



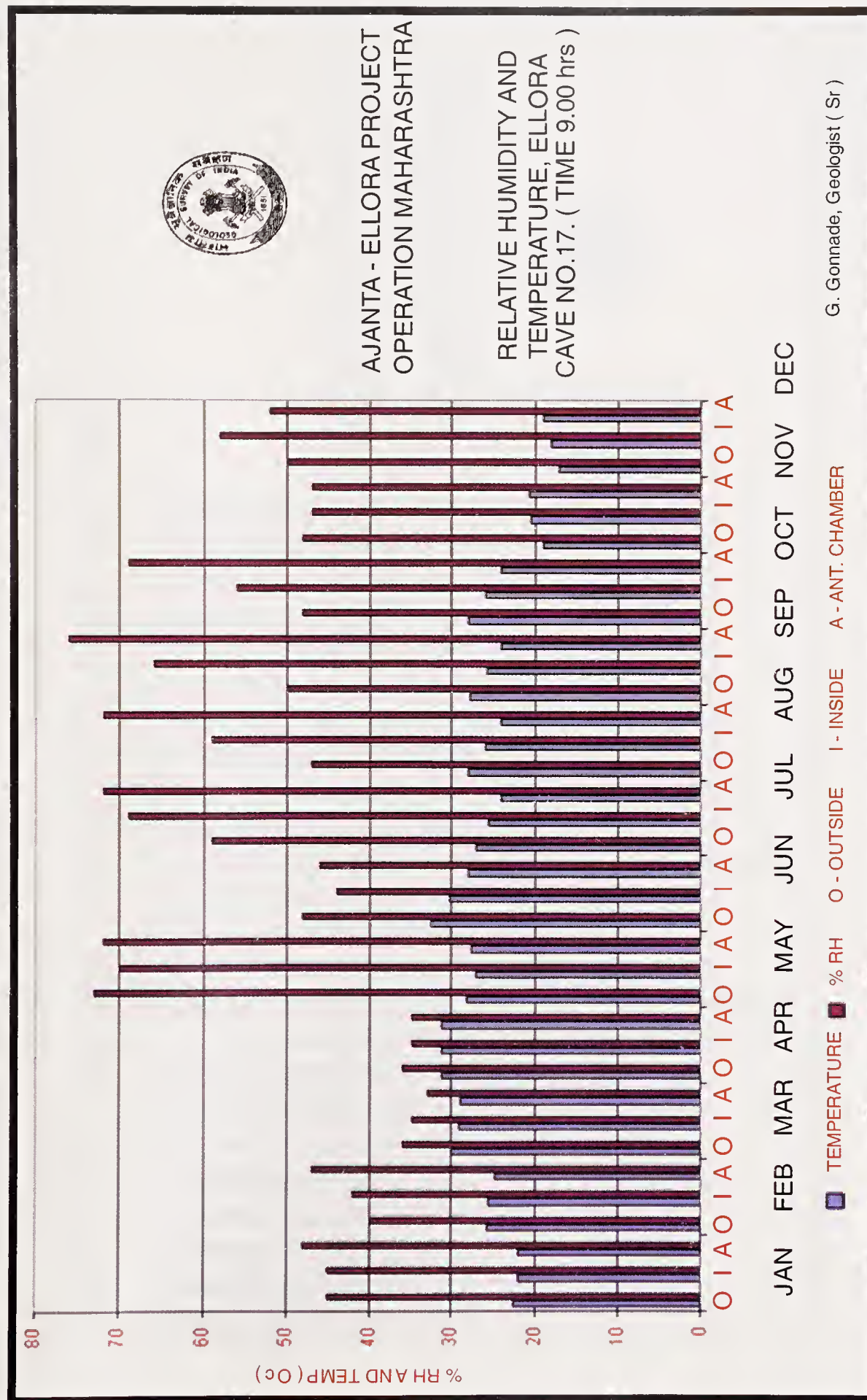
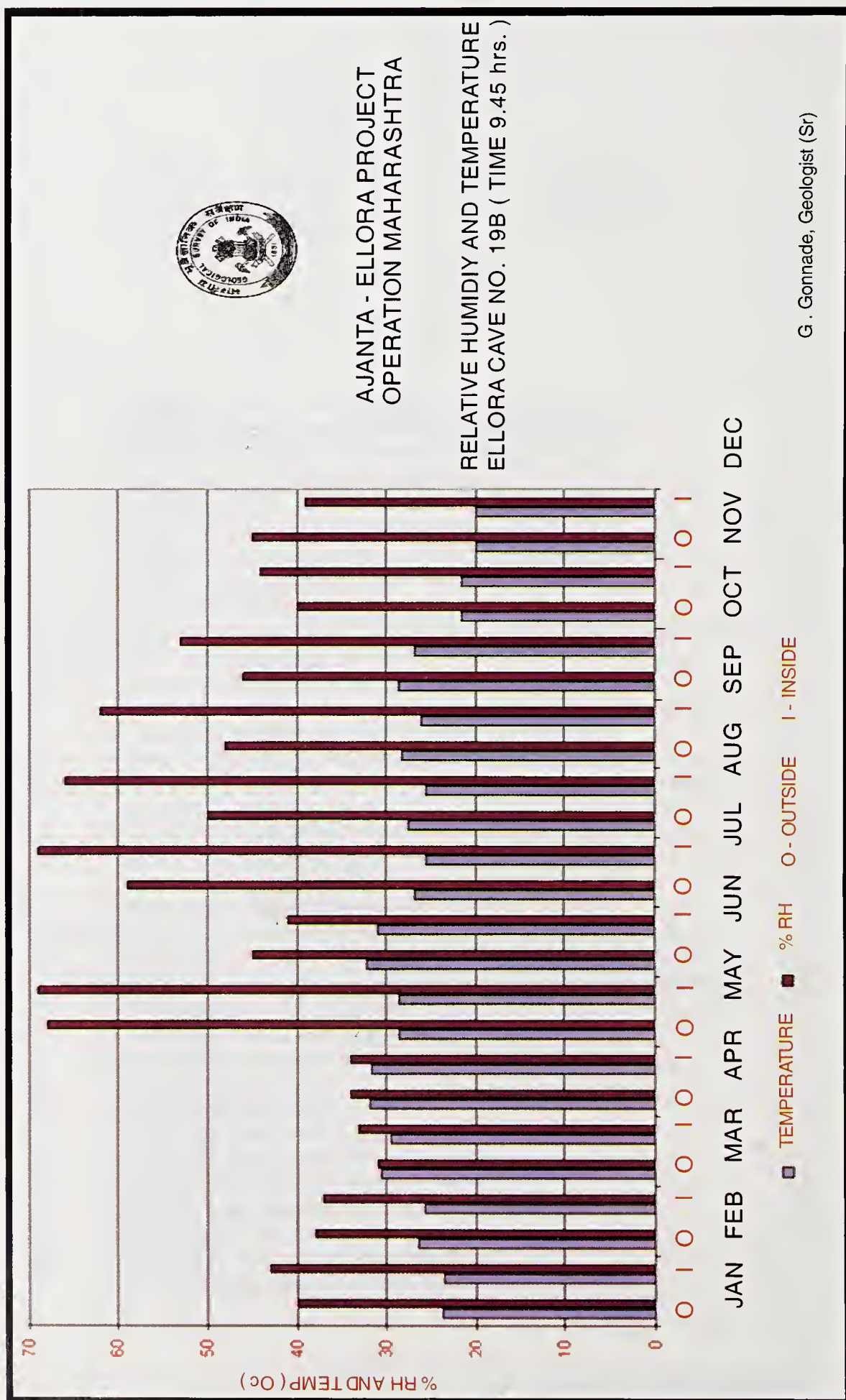


Plate : VIII-13



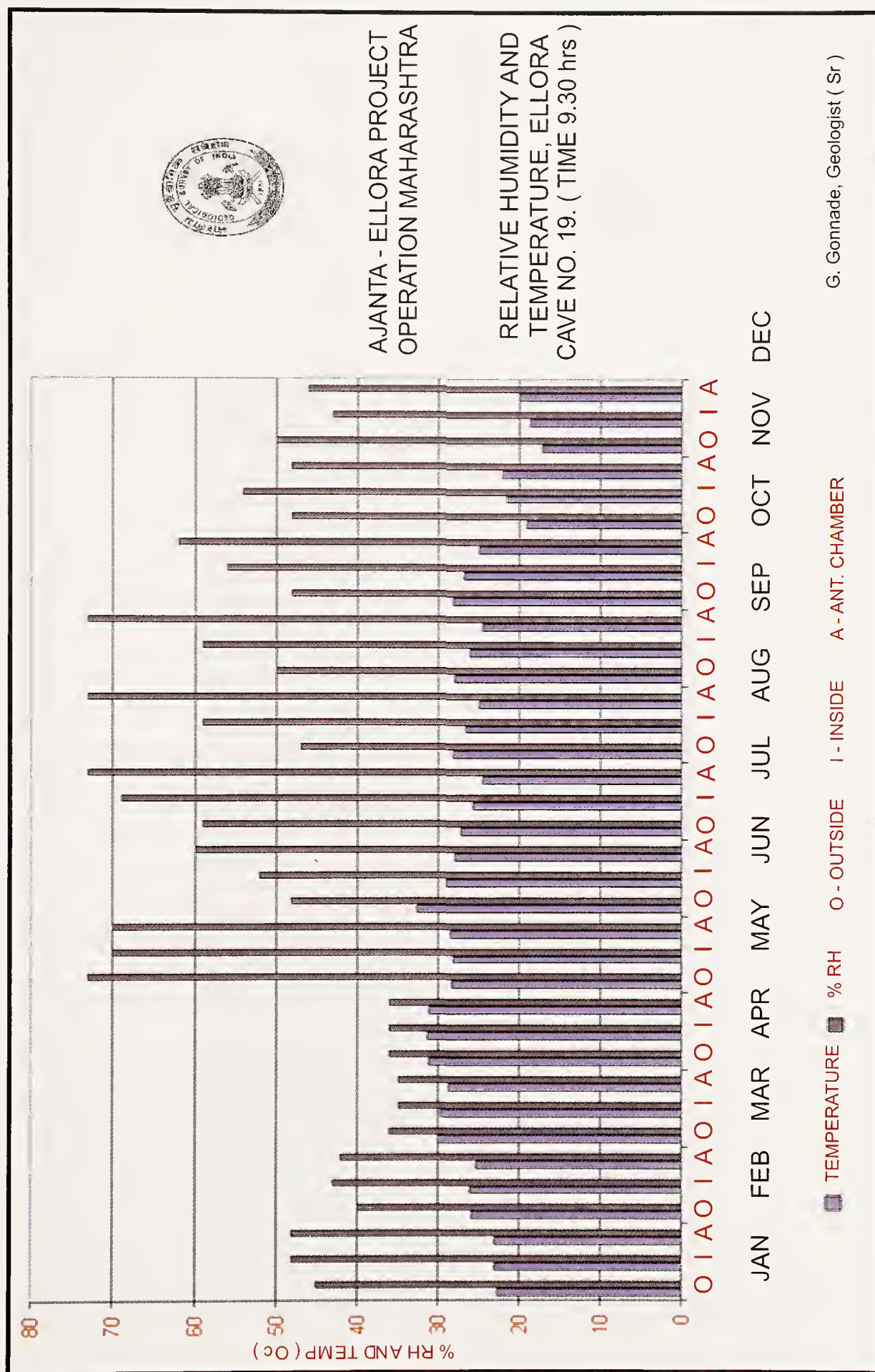
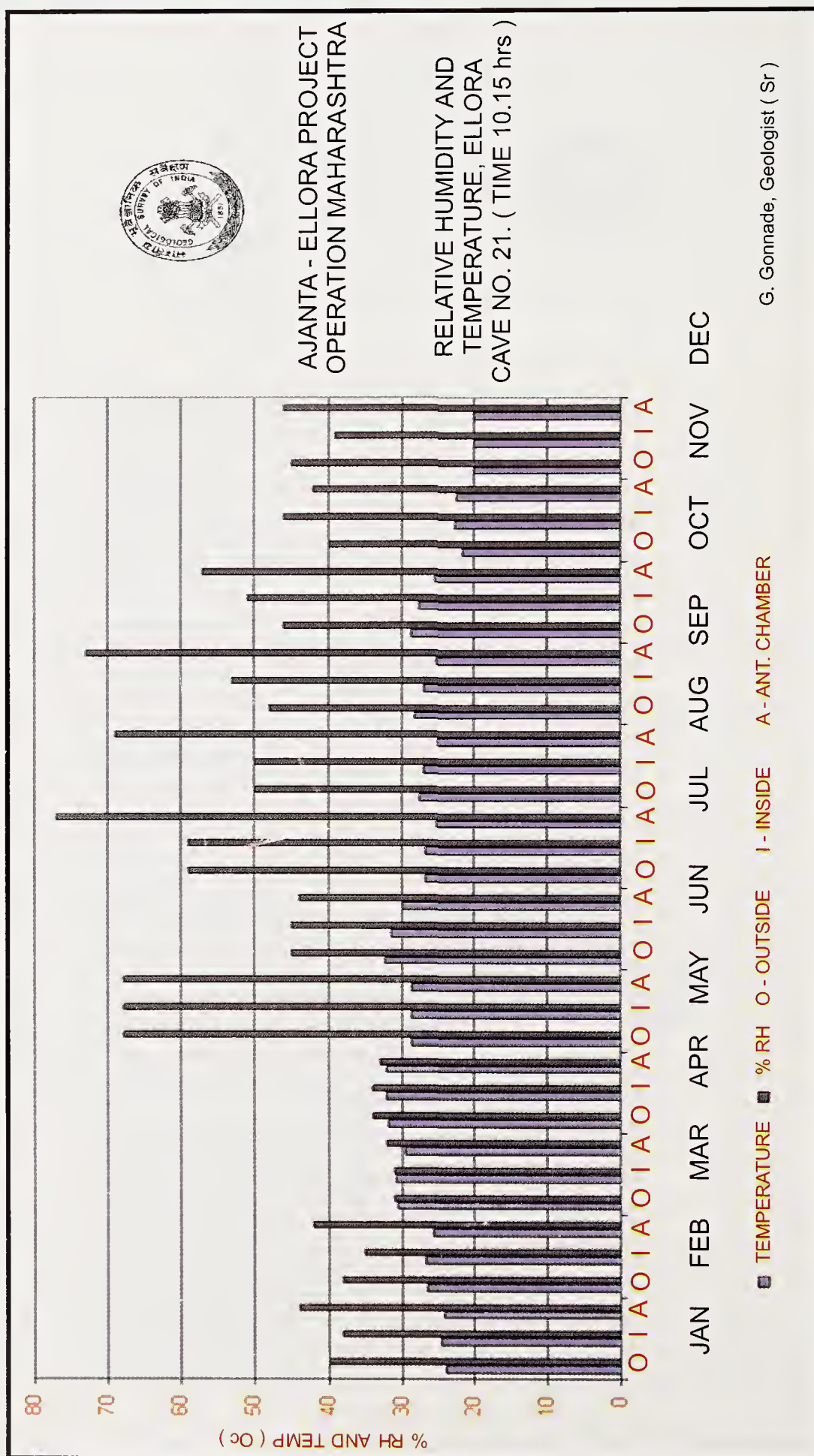


Plate : VIII-15



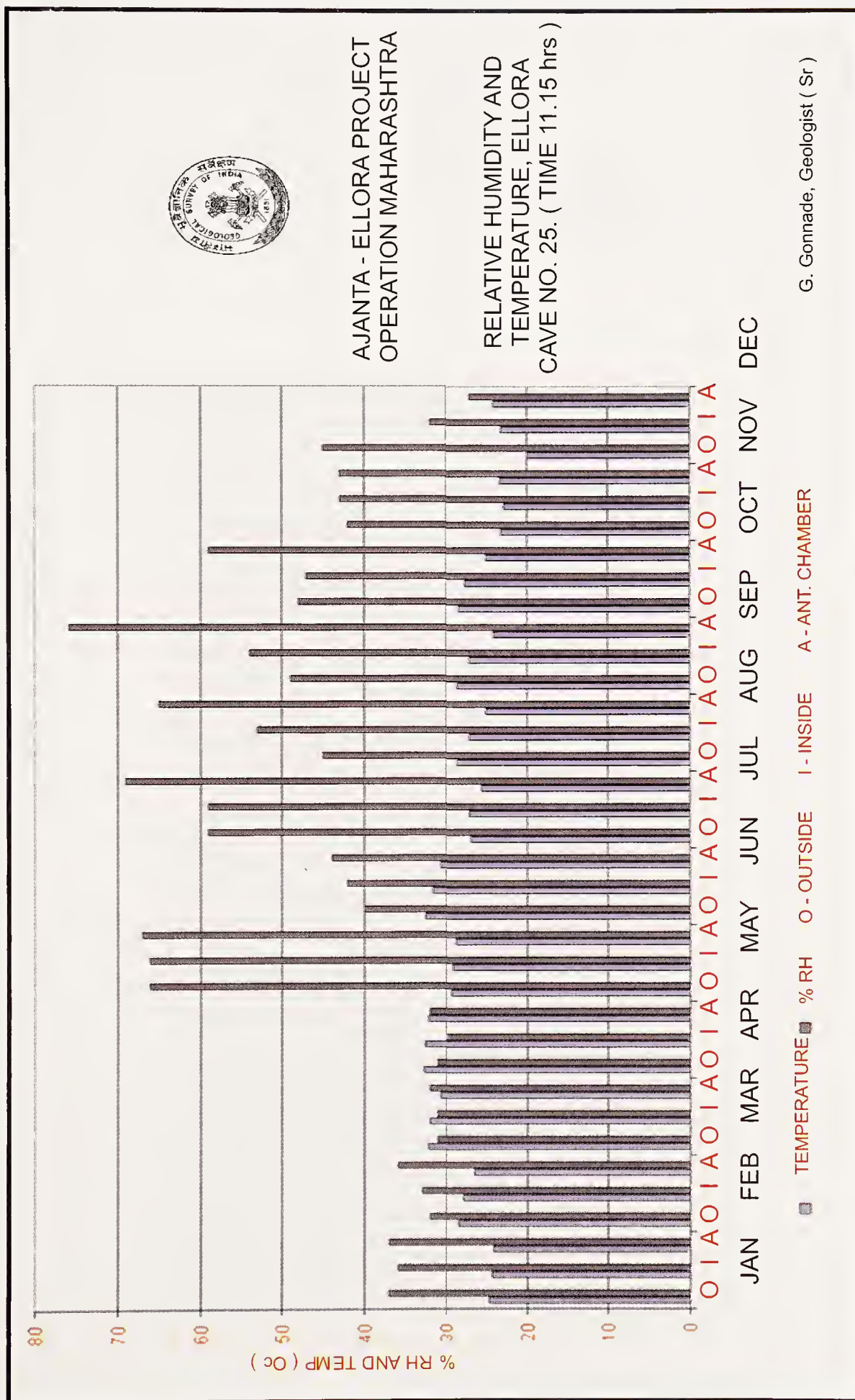
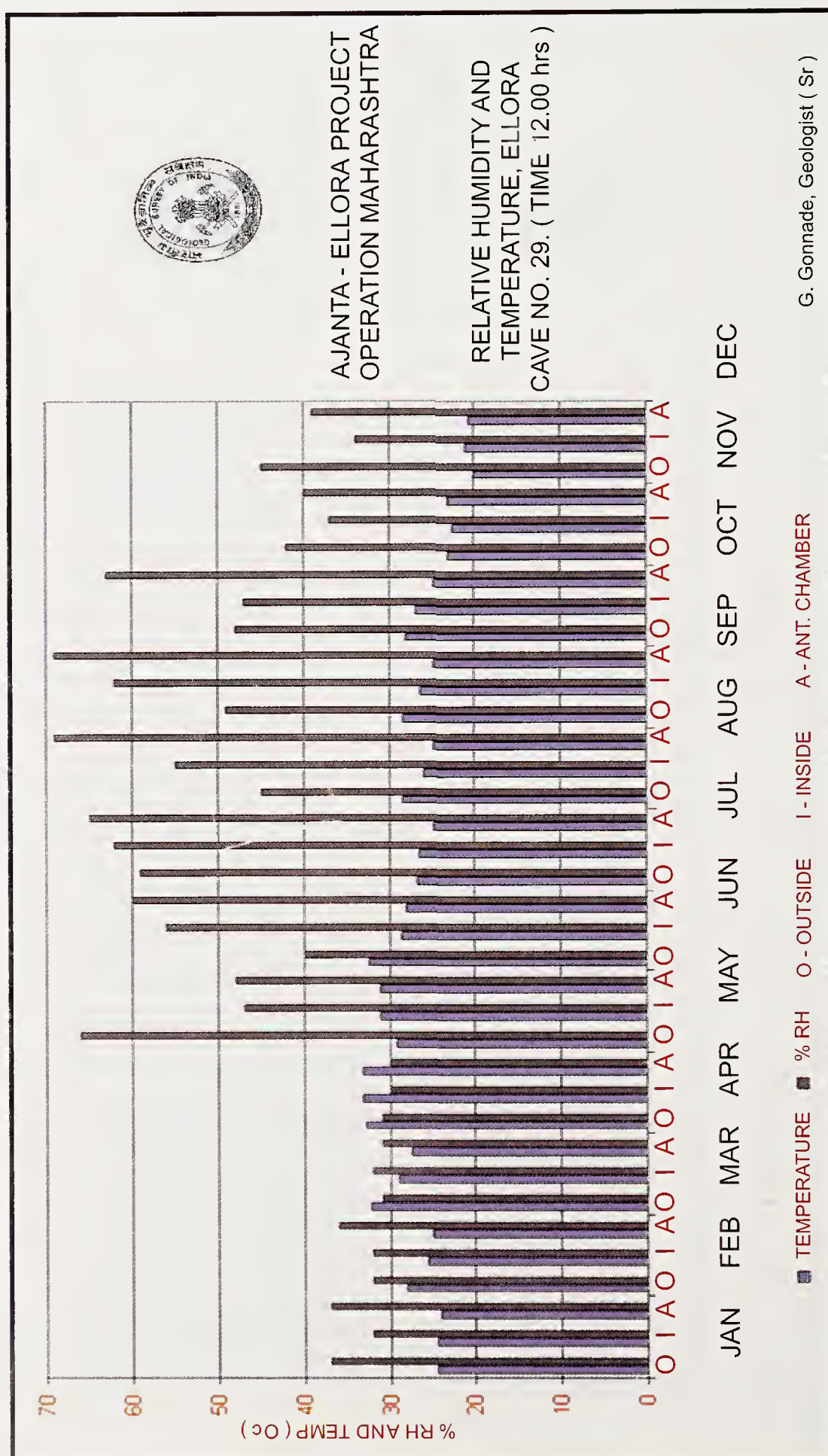


Plate : VIII-17



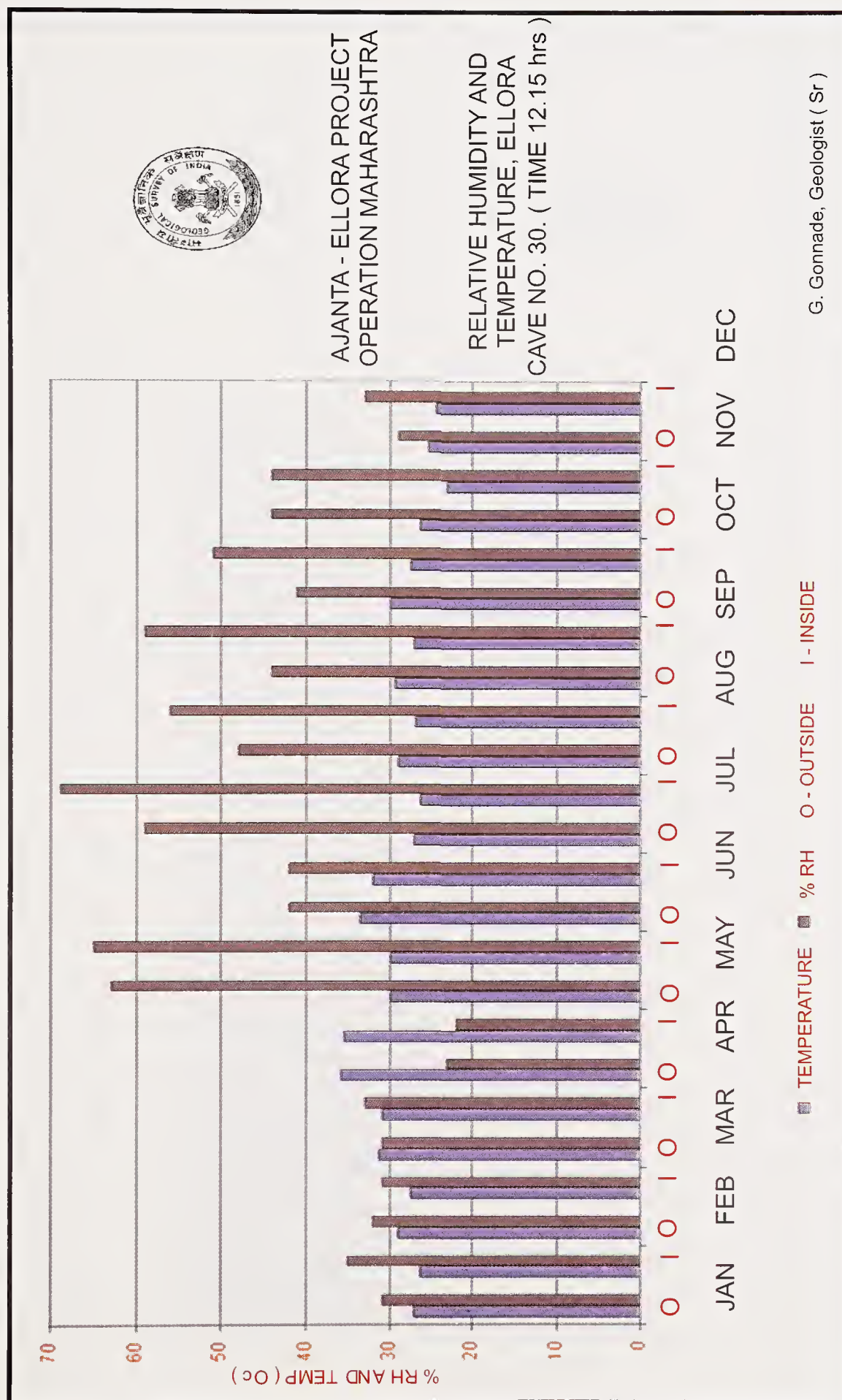
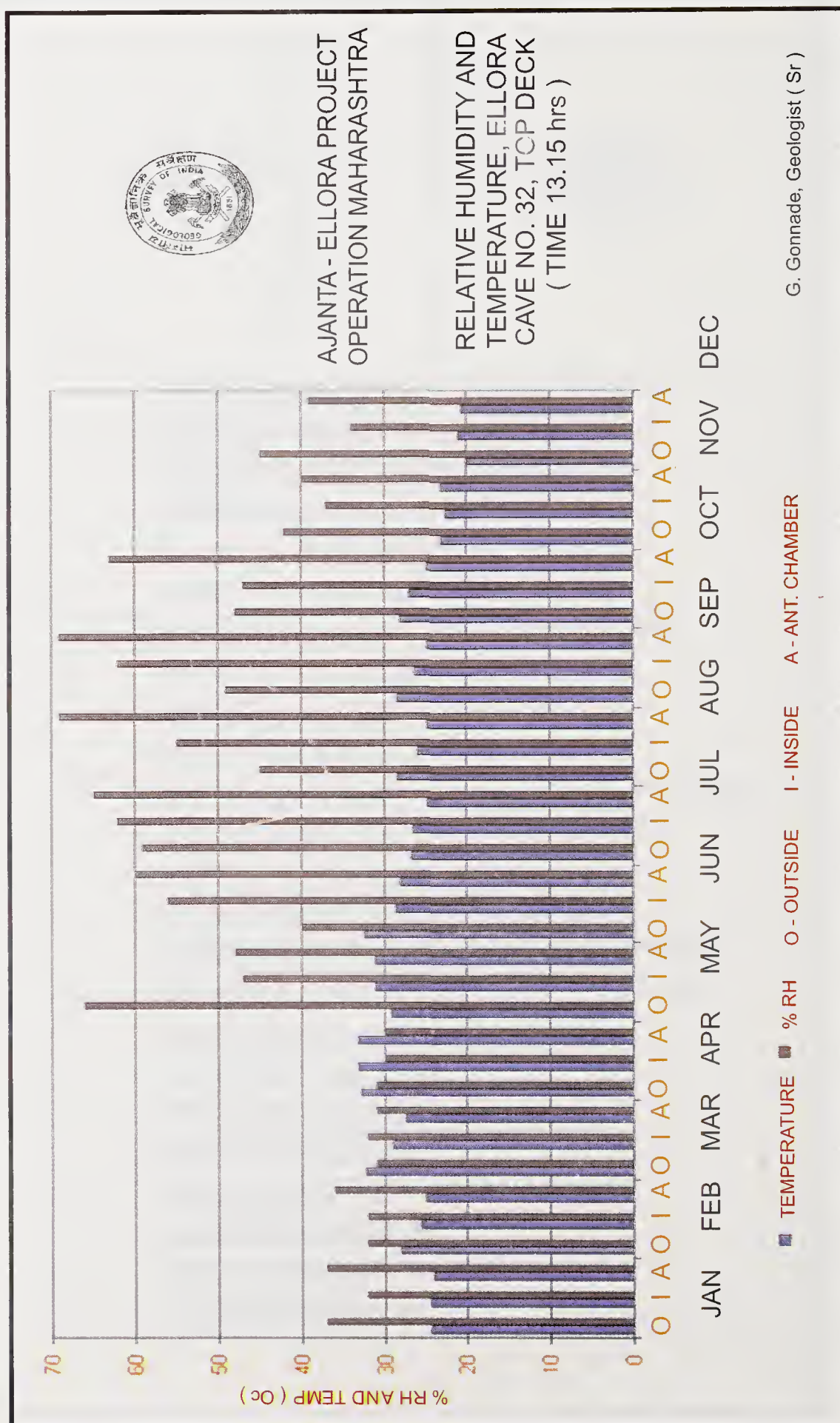
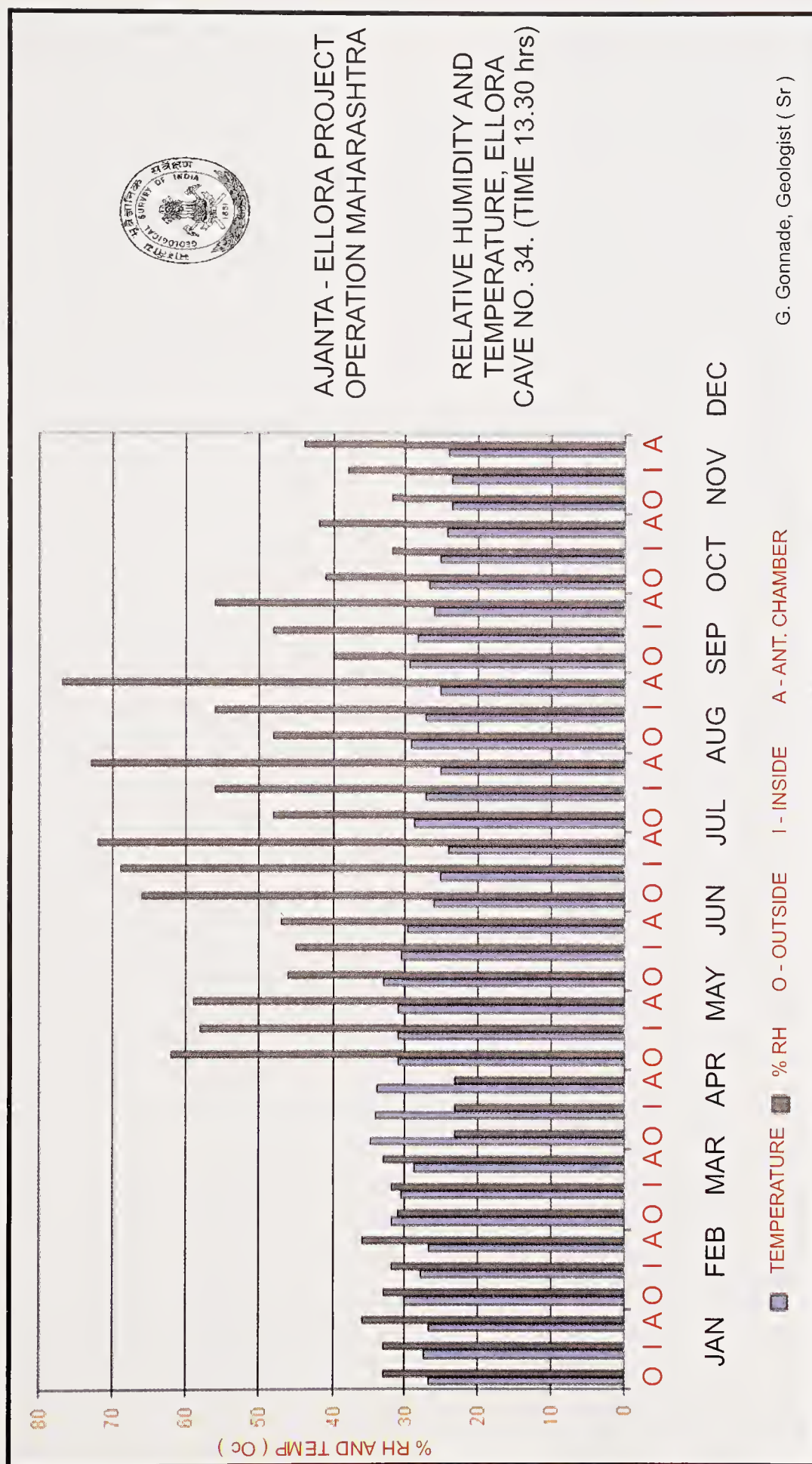


Plate : VIII-19





ENVIRONMENTAL IMPACT ASSESSMENT AND MANAGEMENT PLAN

EXTERNAL ENVIRONS OF THE CAVES

Based on the study of environmental impact due to the tourist influx and developmental activities on the caves' environs, following impacts have been identified and keeping in view the sanctity and aesthetics of the monuments, the following mitigation measures are suggested.

Air quality data reveals that the quality of air deteriorates with the influx of vehicles carrying tourists and deterioration is maximum in summer months. Seasonal average of Respirable Particulate Matter (RPM) and Suspended Particulate Matter (SPM) are as follows :-

Average RPM & SPM values for the year 1999 near cave no. 16, 15 & 32 are 52, 87; 53, 75 and 46, 78 respectively which are within the permissible limit of 75 and 100 mgm/m³. Though the average of RPM & SPM is within the permissible limits, it is on the higher side near cave nos. 16 & 15.

- I. To overcome this, parking place for tourist vehicles may be shifted to a place at least 1/2 km away from the caves and preferably to the left side of Aurangabad – Ellora road and parking place should be tarred.
- II. Ellora caves are facing towards west and throughout the year, most of the time wind direction is westerly. Due to this, whatever dust is being generated in the village or in front of caves is transported to the caves by these winds. To reduce deterioration of air quality due to this condition, the feasibility of planting tall growing trees by the side of road leading to caves, to act as natural receptors to the particulate matter may be examined.
- III. Removal of grass in the caves confines and grazing activities loosen the soil and add to supply of wind blown particles. To reduce concentration of particulate matter in the area such activities should be prohibited (plate VIII-22).

LOCATION	SEASON	AIR QUALITY (μ - gm/m ³)	
		RPM	SPM
Cave 16	Winter	54.54	100.23
	Summer	64.53	111.29
	Rainy	36.93	50.14
	Average	52.00	87.22
Cave 15	Winter	53.15	88.80
	Summer	70.14	138.56
	Rainy	37.74	58.72
	Average	53.66	75.36
Cave 32	Winter	47.00	80.39
	Summer	59.95	102.81
	Rainy	32.05	51.01
	Average	46.33	78.07



- IV. Turfing /paving or a small garden may be developed in front of the entrance of cave 16 to arrest the blowing of sand as particulate matter during dry season.
- b) Removal of the top soil from the cave confines which creates negative visual impact and leads to soil erosion by wind and water, should be stopped and the area should be suitably afforested.
 - c) Noise levels in the parking area are too high during peak hours, which are above the prescribed limits for sensitive zones. Hence the area may be declared silence zone.
 - d) Analytical results of water samples drawn from the streams and storage tank of caves do not reveal presence of anomalous content of any toxic elements. However, bacteriological tests have revealed the presence of total coliform organism. Thermotolerant bacteria were found to be more in water sample drawn from the water storage tank and streams. The water stored in storage tank of caves should be periodically treated. Safe potable water may be made available at cave by extending the existing water supply line. Use of storage tank water for drinking purpose should be stopped. Water vending machines may be installed at 5 to 6 places.
 - e) The entire area of cave from 1 to 34 should be suitably fenced.
 - f) Entry of stray animals should be stopped.
 - g) Foot track on the left side of cave 16 leading to the top of cave 16 is in bad shape and should be remade.
 - h) A toilet near caves 1, 21 & 32 on the lower valley slopes may be constructed with proper and effective waste disposal system.
 - i) Proper garbage collection and its disposal away from the caves' environment should be brought into practice and enforced.
 - j) Wastes which contain mostly polythene packs collected in the dustbins kept near the caves are thrown from the top into the lower valley slopes of streams, and are seen scattered along the slopes. This causes negative visual impact and pollute stream water (plate –VIII 22).
 - k) A foot track leading to cave 25 from cave 24 is in bad shape and it may be the cause of accidents because it passes from the top valley scarp. It should be properly guarded by railing.
 - l) The incidence of tourists is more in cave 16 as they are interested in viewing the cave from top which is not guarded by railing from three sides. Railing by the sides of cave opening on the top, on 3 sides should be constructed for public safety. Foot track from the left side of Khultabad to Cave 16 opened for public use, may lead to accidents. It should be guarded by the railing on the roof - top of cave 15 or from the left side of foot track near cave 15.
 - m) The rocks of caves 31 to 34 are highly fractured and cracks are prominent. Vibration due to vehicles may create negative impacts on stability of these rocks in long run. To reduce such ground vibrations entry of heavy vehicles up to the gate of cave 32 should be banned.
 - n) A R.C.C. structure constructed for office between cave 16, and 15 by the side of



road leading to cave creates negative visual impact and reduces aesthetic value of cave 16. It should be removed (Plate VIII -22).

INTERNAL ENVIRONS OF CAVES

Based on the negative impacts identified during the course of studies on cave's internal environment on account of the tourists influx, following mitigation measures are suggested:

- a) To reduce the dust carried by the tourists along with their footwear, all the entry points should be covered with wire mesh, poly grass, Astroturf's etc., for suitable lengths.
- b) Sweeping of the cave's floor daily generates fine dust particles and larger part of it gets circulated within the cave and settles on the walls. This practice of dusting in the cave nos. 16 (main temple), 32 and 34 should be discontinued and vacuum cleaning twice a week should be sufficient to remove the dust from the caves. For this purpose noise proof vacuum cleaners may be used.
- c) Use of caves for storing building material such as cement and chemicals should be avoided.
- d) Noise levels in caves increase during peak hours and are above the prescribed limit for sensitive zones. Unguided groups of visitors (mainly school children) produce higher noise levels, which may have negative impact on cave's paintings in long run. To keep the noise levels within tolerable range, people should be cautioned by proper guidance and suitable and sufficient display of posters/pamphlets at entry points specially at caves 10, 16 (main temple), 32 (top deck) and 34 (top deck).
- e) Data generated from Micro Earth Quake studies (refer for detail MEQ Studies in chapter VI) reveal that the noise levels near cave nos. 10 and 16, are ten times higher than the natural background values. Hence parking area and the State Highway needs to be shifted away by at least 1 km from the present locations. The entry of vehicles upto the cave 10 should be stopped.
- f) Data collected on humidity and temperature inside the caves having paintings reveal that the seasonal weather changes influence the humidity levels, which in long run may have detrimental effect on paintings. To minimize this, suitability of installing humidity control equipment should be explored.
- g) Bats are nesting in caves 5, 12, 16, 19, 25, 29, 30 & 32. These produce black and white patches on the sculpture, walls and bad odor in the caves. Such caves should be covered with doors/wire mesh after driving off the bats or sufficient lighting arrangement inside the caves should be done.
- h) Existing railing at Chikni Lanka (cave 16) is not up to the full length and it should be extended up to the next wall. Entry to the cave no. 4 should be banned till the repairs are undertaken (Plate VIII - 21).
- i) Water storage tanks inside the caves 10, 11, 12, 17 & 27 are deep and open. These may cause accidents and should be covered.
- j) Stairs of cave 16 especially in Pad Lanka access from middle deck to top deck are slippery. They should be repaired and lighted properly. Similar measures should be taken for the stairs of Chikni Lanka.



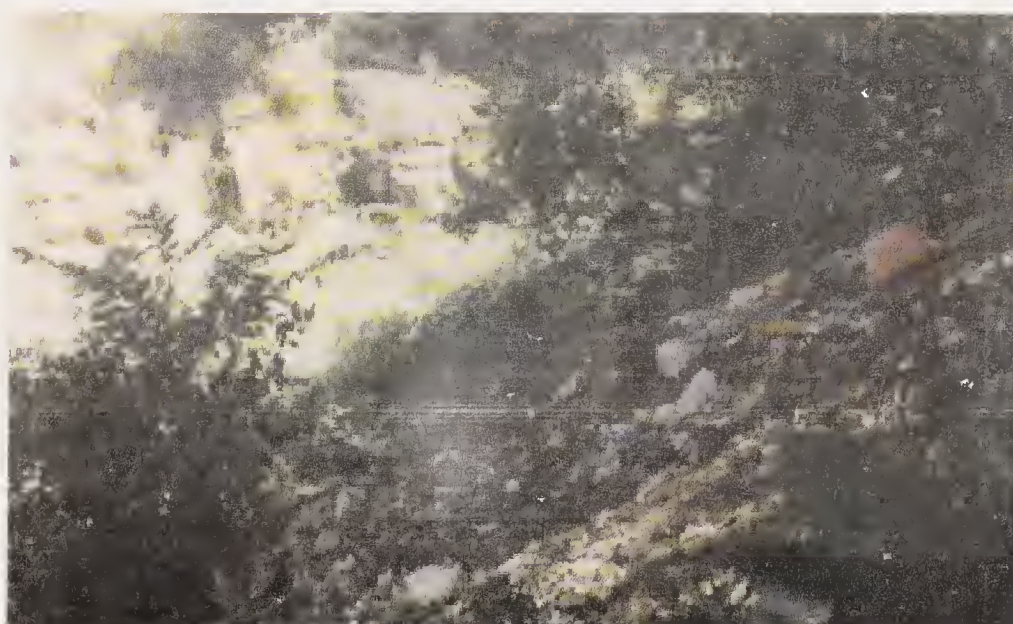
Plate : VIII-21



CAVE 16 –
GRAZING BY
STRAY ANIMALS
IN VAST OPEN
SPACE.



BETWEEN CAVE
15 & 16 –
RCC STRUCTURE
DETERIORATING
ASTHETIC VALUE
OF THE
MONUMENT.



VALLY SLOPE
NEAR CAVE 16 -
DISPOSAL OF
SOLID WASTES
CREATING
NEGATIVE
VISUAL IMPACT
AND POLLUTING
STREAM WATER.



**CAVE 4 –
UNGAURDED
FLOOR AND
STAIRS LEADING
TO IT.**



**CAVE 2 – GROWTH
OF BIOMASS
DEGENERATING
THE ROCK.**



**CAVE 16 –
SCULPTURE
LOOSING DETAILS
DUE TO PHYSICAL
WEATHERING**

Table VIII- 1

WEATHER MONITORING AT ELLORA CAVES

MONTH	TEMPERATURE °C		% RH		PREVALENT WIND DIRECTION	RAINFALL IN MM.
	MIN	MAX	MIN	MAX		
JANUARY	10	33	30	68	NORTHERLY, NORTH - WESTERLY	512 (FROM 20.6.99 TO 25.10.99).
FEBRUARY	14	33	27	88	NORTHERLY, NORTH - WESTERLY	
MARCH	19	39	27	89	NORTHERLY, NORTH - WESTERLY	
APRIL	17	42.3	13	70	WESTERLY	
MAY	20.5	44.1	13	99	WESTERLY	
JUNE	20	37.8	25	99	WESTERLY	
JULY	20.2	35.5	47	99	WESTERLY	
AUGUST	19.5	32.3	58	99	WESTERLY	
SEPTEMBER	19.5	31.4	60	99	WESTERLY	
OCTOBER	16.2	32.9	30	99	EASTERLY , NORTH - EASTERLY	
NOVEMBER	17.2	33.7	25	89	NORTHERLY, NORTH - WESTERLY	
DECEMBER	13.6	35.9	24	72	NORTHERLY, NORTH - WESTERLY	

AIR MONITORING AT ELLORA CAVES

Table VIII-2

LOCATION	PARA-METR	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC
	SPM	97.09	101.78	125.26*	180.84*	89.46	49.61	44.77	48.42	64.10	43.30	124.31	74.74
CAVE 16	RPM	53.65	76.66*	82.08*	118.89	23.70	33.45	28.29	29.44	52.54	37.46	49.93	37.93
	NO2	5.025	3.075	1.70	9.33	7.05	7.19	2.46	3.46	4.40	2.075	15.8	24.45
	SO2	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1
	SPM	83.24	95.20	210.64*	200.08*	97.22	46.32	43.69	73.36	58.29	59.54	90.07	86.70
CAVE 15	RPM	61.99	73.08	116.01*	102.99*	30.86	31.08	26.72	39.72	42.69	41.86	33.95	43.58
	NO2	8.275	3.825	2.60	7.125	11.460	11.5	4.26	8.17	7.20	1.40	2.725	7.375
	SO2	<1	<1	<1	<1	<1	1.86	<1	<1	<1	<1	<1	<1
	SPM	95.55	77.97	130.77*	172.53*	48.15	59.79	45.80	34.49	59.67	64.08	71.31	76.74
CAVE 32	RPM	56.50	63.26	92.79*	80.41*	24.22	42.39	25.45	18.99	39.46	44.31	34.84	33.415
	NO2	6.275	1.60	1.829	7.950	9.00	1.11	1.91	2.60	7.52	9.2	<1	<1
	SO2	<1	1.5	<1	<1	<1	<1	<1	1.15	<1	<1	<1	<1
	SPM								35				
CAVE 10	RPM								16.17				
	NO2								5.25				
	SO2								<1				
	SPM								29.74				
CAVE 20	RPM								19.95				
	NO2								6.675				
	SO2								3.5				

*Permissible limit for sensitive area : SPM-100, RPM-75, NO2-30, SO2-30

Values in $\mu\text{gm}/\text{m}^3$

WATER QUALITY AT ELLORA CAVES

SL NO	CHARACTERISTIC	TOLERANCE LIMIT AS PER 2296 CLASS A	SURFACE WATER		STORAGE TANK WATER		SEEPAGE WATER
			WINTER	SUMMER	WINTER	SUMMER	
PHYSICAL PARAMETERS							
1	pH	6.5 TO 8.5	7.40 – 7.60	8 – 8.10	5.90 – 7.60	3.60 - 8.20	7 – 7.9
2	Cond. At 25°C micro-omhs/cm	800	385 - 445	345 – 489	139 – 386	163 - 757	139 – 522
MAJOR MINERAL CONSTITUENTS in ppm							
3	TDS	500	279 – 346	275 – 357	107 – 438	108 - 670	261 – 496
4	TOTAL HARDNESS AS CaCO3	300	188 - 190	166 – 181	74 – 190	55 - 207	118 – 240
5	POTTASIUM	20	3 - 4	4 – 5	2 – 17	2 - 16	<1 – 20
6	CALCIUM	75	28 – 30	36 – 38	20 – 55	24 - 54	29 – 61
7	CHLORIDES	250	12 – 18	26 – 56	6 – 23	8 - 970	10 – 31
8	SULPHATES	400	28 – 34	10 – 20	7 – 70	8 - 212	29 – 61
9	SODIUM	200	50 – 66	52 – 78	20 – 41	44 - 62	28 – 65
10	FLORIDES	1.5	< 0.50 – 0.50	< 0.50	0.50	< 0.50	<0.50 – 0.50
11	IRON	0.3	< 0.1	< 0.1	< 0.1	< 0.1	<0.1
12	BORON	2	< 0.50	< 0.50	< 0.50 – 0.50	< 0.50	<0.50 – 0.50
13	MAGNESIUM	100	27 – 30	17 – 22	6 – 17	1 - 17	8 – 22
14	SILICA		20 – 30	3 – 26	9 – 28	11 - 36	31 – 51
15	HCO3		244 – 320	169 – 241	76 – 203	12 - 220	154 – 305
TOXIC METALS in ppb							
16	COPPER	50	5 – 10	10 – 30	< 5 – 10	< 5	<5 – 10
17	NICKEL	3000	< 10 – 10	<10 – 40	< 10 – 10	<10 - 40	<10 – 10
18	CADMIUM	10	< 2	< 2	< 2	< 2	<2
19	ARSENIC	50	< 10	<10 – 10	< 10	<10	<10
20	LEAD	100	10	20 – 60	<10 – 10	<10 - 40	<10 – 10
21	ZINC	5000	< 2	<2 – 10	<2 – 10	<2 - 10	<2 – 10
22	MANGANESE	100	< 5	110 – 190	< 5 – 40	5 - 80	<5
23	COBALT		< 10 - 10	10 – 20	< 10	<10 - 30	<10 – 10

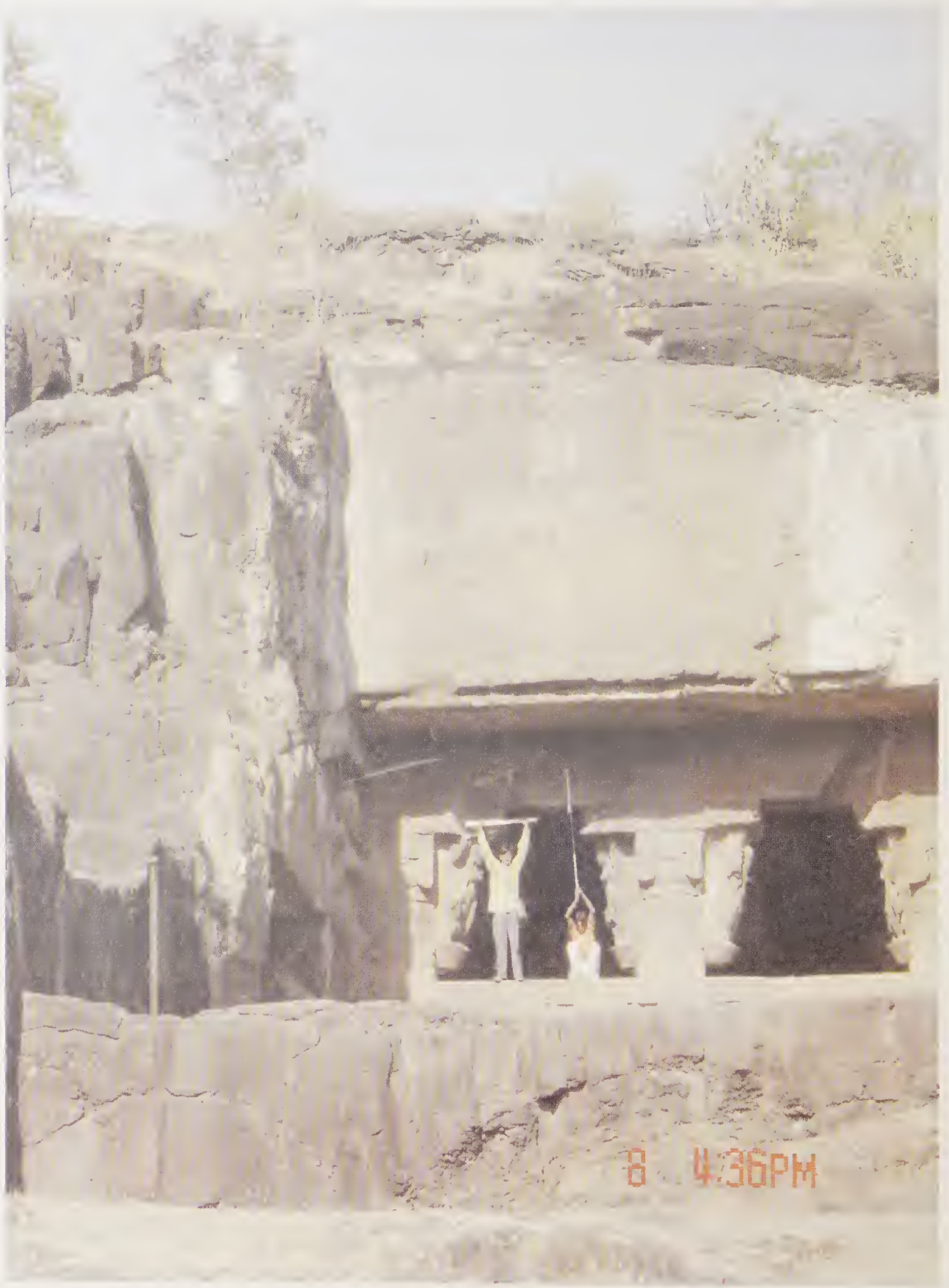
Table VIII – 4

**RESULTS OF BACTERIOLOGICAL TEST OF WATER
SAMPLES; ELLORA CAVES AREA**

Location	Coliform / 100 ml.	Thermo tolerant Bacteria / 100 ml.	Remarks
Storage tank water, cave 29	>16	6	Not potable
Stream water near culvert cave 29	>16	9	Not potable
Stream water above cave 5	>16	9	Not potable
Storage tank water, cave 11	>16	16	Not potable
Storage tank water, cave 12	>16	9	Not potable
Storage tank water, cave 15	>16	3	Not potable
Stream water near cave 16	>16	6	Not potable

CHAPTER IX

**SUMMARY
CONCLUSIONS
AND
RECOMMENDATIONS**



CHAPTER-IX

SUMMARY, CONCLUSION AND
RECOMMENDATIONS

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IX. SUMMARY, CONCLUSIONS AND RECOMMENDATIONS

SUMMARY AND CONCLUSIONS

The rock cut temples of Ellora, bestowed with world famous sculptures and paintings representing three religious faiths, have suffered considerable damage due to natural process of weathering and human interference. Unstable slopes, seepage and environmental degradation are of major concern while preserving the cave monuments for posterity.

The area under study forms the eastern valley margin of Shivna sub-basin of Godavari Main Basin and is marked by steeply rising N-S trending plateau popularly known as *Maismal Plateau* in the east and Shivna plains in the west. The southeastern part of the *Maismal Plateau* is dissected and forms the northern valley margin of Purna sub-basin of Godavari Basin.

Ellora caves are located in the Deccan Volcanic Province which forms a part of lava plateau with a relief of 300m with maximum and minimum elevation of 800 m and 550 m above msl respectively. Eight geomorphic units have been identified in the area including alluvial plains, undulating plains, badlands, ridge and valley, plateau remnants, dissected plateau, high level plateau, and residual hills.

The lineament fabric of this area exhibits four major sets of lineaments trending in the NE-SW, NW-SE, N -S and E - W directions. Intersections of these lineaments have given rise to prominent scarps, linear ridges, narrow valleys with high angled scarps and rectilinear drainage. From the analysis it appears that the NE-SW trending lineaments are the oldest while those along east- west are the youngest.

Badland development with rills and gullies, seen to the north and south of Ellora, presence of waterfalls along streams like Jogeshwari nala, coupled with steepness and straightness of the scarp are suggestive of tectonic disturbance. As a result, in some of the caves minor slips/ displacements are noticed which are intersected by a roughly east-west trending lineament passing through the hill ranges. Alignment of the gaps across spurs/ ridges, extending towards SE from 846m peak and presence of a spring on the loci, points to possibility of another fault/fracture trending in NE-SW direction.

Regionally three planation surfaces are recognised in the area. They are E_3 planation surface, E_2 planation surface, known as Maismal Plateau, and E_1 planation surface. T_1 terrace and T_0 Terraces are the depositional surfaces. Two *planation surfaces* (E_2 and E_1) have been recognised in the Ellora caves area. The present flood plain of the Waghur constitutes the T_0 surface. The landforms identified in the caves area include entrenched valley, rapids, potholes and thalwage.

A prominent scarp face about 160m in height between 640m and 800m is seen along the north- south trending, eastern valley margin of Shivna river. The slopes in the scarps are predominantly steep with intermittent moderate and at place precipitous slopes, thereby giving rise to small flats and overhangs



respectively. This scarp is further sub-divided into upper scarp S_1 and lower scarp S_2 .

A N-S trending water divide exists between Shivna and Purna sub basins. The Shivna and Purna rivers are fourth order consequent streams having perennial flow. Secondary drainage pattern in the area is mostly subdendritic and sub-parallel. First order and second order streams exhibit trellis pattern. Streams originating from E_3 and at places from E_2 surfaces show radial drainage pattern. East of the water divide, the streams show higher sinuosity, sharp turns and meanders constituting rectangular and sub parallel patterns.

Slopes, surfaces and flats in the study area around the Ellora caves are occupied by soils and scree. Different types of soils and scree identified in the area are black cotton soil, inceptisols, transported silty soils, matrix supported and mostly clast supported scree in the higher reaches.

Slope map for about 0.15 sq. km area in the immediate cave environs has been prepared based on the topographic map (1:500 scale) and seven categories of slope segments have been identified and demarcated. Out of these, category I slopes are most vulnerable and need protection measures and category V slopes provide land having high land use value.

The plateau area exposes the Upper Ratangarh Formation comprising 7 flows of which five are compound pahoehoe and two are Aa flows. The topmost flow is a megacryst flow, which is a regional marker flow in the area. The thickness of individual flow ranges from 15 to 32 m.

The Ellora caves area is occupied by two *basaltic flows* belonging to the Upper Ratangarh Formation. The flows are of compound pahoehoe type with well-developed basal pipe vesicles, pahoehoe toe and ropy surfaces. FLOW I is 50-60m thick and consists of 15-18 units, with thickness of individual unit varying from 2 to 6m. The pahoehoe unit comprises a top vesicular zone, a middle massive part with widely spaced vesicles in some cases and a thin bottom vesicular zone with longitudinal, bifurcated basal pipe vesicles. The top surface generally shows a thin reddened crust and at many places ropy structures. All the caves in Ellora area are carved out of the lower units (1-10) of this flow. FLOW II is about 60m thick and consists of 15-18 units with similar unit characters as flow I. The top contact of this flow is not exposed in the area mapped.

Different primary structures observed in the area include polygonal cooling joints, ropy structures, pahoehoe toes, pipe amygdules, vugs/cavities, lava tunnels, in-crack fillings and squeeze ups. The secondary structures seen in the area are four prominent sets of joints, relief joints and exfoliation joints.

Petrochemical studies of basalt samples reveal that basalts are predominantly quartz normative tholeiites. The magma from which these rocks are formed seems to be of highly evolved nature with initial iron enrichment followed by depletion of MgO. Some flow/ units though tholeiitic, show a marginally higher alkaline nature.

The presence of four sets of joints, three vertical and the fourth, a set of steeply dipping relief joints along with the fracture zone and cooling cracks, has accentuated weathering and rendered the cave facades and certain slope segments weak. Wherever the fracture zone has intersected the cave openings,

outer portions of the caves have collapsed as seen in caves 1-4, 13 and 14. The relief joints with progressive undercutting of toe have played a major role in the retreat of the slope by about 5m.

Terrestrial stereo-photographic methods have been used to prepare and critically study rock mass distribution and slope protection maps. Characterization of rock mass was carried out on the basis of three basic parameters of relative strength, joint volume and relative weathering. Analysis of rock mass distribution maps was done to determine selective protection/ treatment measures by dividing the slope into four sectors.

The assessment of slope stability in different sectors reveals that:

Sector I (caves 1 – 7): The rock mass is of 'Mms' type with local 'Lcm' patches in the flow contact zones. The vertical joints set (J_2 and J_3) and the fracture zone in combination with the J_1 set of joints have rendered the frontals of caves 1 to 5 unstable (facades of most of these caves have collapsed) and accentuated seepage in the outer 1 – 2m zones of caves 1, 2 and 4. No seepage is seen in caves 5, 6 and 7. The presence of relief joints/cracks in the outer 5 m zone is the causative factor for seepage inside the caves. The nala above cave 5 with large potholes does not contribute to seepage in the caves but needs attention to prevent the possibility of seepage in future.

Sector II (caves 8 -16): The rock mass is mostly of *Mms* type with *Lcm* type in the unit contact zone. The presence of relief joints (J_4) along with cooling cracks has accentuated weathering of slopes. The seepage in the caves is confined to the outer 1-2 m zone of relief joints. The dense basalt with predominant basal set (J_1) and the flow contacts at the roof level of caves – 10 and 16 (side caves) have caused local gravity falls.

Sector III (caves 17 – 30): The rock mass in general is 'Mms' and 'Mcs' type with patches of 'Lcm'. The weathering (Grade III/II) is very pronounced in the caves and outer slopes. The vertical sets of joints (J_2 and J_3) in combination with the basal set (J_1) have caused wedge failures in the frontals of cave: 17, 18 and 21. Prolonged erosion along the unit contact has formed negative/reverse slopes (caves 19, 20, 21, 25, 26, 28) that have made the cave frontal slopes critical with overhangs. Accentuated seepage is seen in the outer relief zone of cave 17.

Sector IV (caves 31 – 34): The rock mass in general is of 'Mms' and 'Mcs' type with few patches of 'Lcm'. The relief joints (J_4) with dips of 50-65° towards SW in the outer zone of 2-5 m. have made the slopes critical at certain locations. The weathering (Grade III and II) is very pronounced in the cave surroundings. Seepage in the outer zone of 2-3 m. with relief joints is very pronounced.

Slope protection maps have been prepared based on the rock mass distribution, suggesting areas requiring specific treatment like shotcrete (25-50 mm.), reinforced shotcrete, with wire mesh (100 mm thickness), rock bolts and anchors (20-25 mm diameter; grouted, tensioned).

While preparing *cave maps* on 1:50 scale, the cracks/ fractures were graded from I to V based on hazard potential, length of the crack, its orientation, aperture, healing, filling, depth, roughness and inclination. The cave wise summary is as follows:

CAVE 1: Structures in the outer 9 m wide zone have been destroyed. Above the entrance of the cave, weathering has resulted in creation of an overhang in which some portions have been dislocated. The facade of cave 1 can be divided into three zones. The lower part, immediately above the crown of the cave and upto the drain, shows moderately weathered rock with biogenic growth. Seepage in the form of droplets is seen at a number of places through the cracks developed in the weathered rock. The second zone extends from the drainage up to the negative slope developed due to differential weathering in the highly fractured zone serving as conduits. The third zone is above the negative slope that forms an overhang. The outer half part of the hall of the cave has developed cracks. Near the entrance one small block has started opening up and is likely to fall any time. Seepage in the cave is restricted to the outer 1-2 m of the hall and the first cell on the right.

CAVE 2: In the verandah seepage is seen through a crack on the right side. The facade of cave 2 has been divided into three zones. The lower zone consists of the plastered portion. Above this, the weathered rock forms the second zone. This zone is fed by rainwater percolating down through the highly fractured zone and that in turn feeds the lower weathered zone concealed by plastering. The upper zone and the third zone forms a slight overhang at places and does have seepage problem. Only minor fractures are observed in the cave and seepage is through a crack above the window, seen in the front aisle, at the contact of the wall and crown.

CAVE 3: The outer part consisting of a verandah has been destroyed. Above the cave, part of extensively weathered overhang has been dislodged. A portion of the crown of the front aisle has also collapsed. One major crack runs across the third cell on right, right aisle, beam on the right, central hall, left beam and left aisle. Within the cave the crack is wider towards south and narrows towards the north. There are no fractures in the shrine. Some seepage is seen from the facade along a unit contact. The water channel, running from cave 5 up to cave 1, constructed above the cave, seems to contribute to the seepage.

CAVE 4: The outer 6 – 6.5m deep portion of the cave has collapsed. The original cave might have consisted of an outer verandah, a central hall, an outer chamber and shrine on the lower deck facing west. On the upper deck, the cave probably consisted of a verandah, an antechamber, a shrine with walk way and cells on either extremity. Out of these, a part of hall, outer chamber, shrine on the lower deck, small part of the verandah, outer chamber, half of the shrine, the cell on the eastern sides and part of the walkway now exist. There are numerous cracks on the crown of the lower deck. The roof of the lower deck is about 90 – 95 cm thick. The cracks developed in the walls of the upper deck were repaired by insertion of clamps and grouting with cement mortar. Similarly the floor of the upper deck was extended, using RCC, by about 1-3m. This additional load has resulted in the development of cracks in the walls of the shrine and the door of the walkway and in the walls of the cell on the eastern side. Seepage from the façade is through the weathered basalt (showing exfoliation weathering) and unit contact, in the form of droplets.

CAVE 5: The front aisle, the crown, right cell and pillars of the cave have partially collapsed. There is a potential zone of rockfall in the right aisle.



CAVE 6: The outer 3-4m deep part including outer wall of the right hall supporting the crown at the outermost extremity and part of the crown at two different levels along two unit contacts of the cave have collapsed. Casts of ropy structure are seen wherever roof has collapsed. The crown of the central hall that is higher than the two side-halls show trace of unit contact and a category V fracture, trace of which can be seen in the window recess and the walls. This crack can be seen day-lighting on the outer wall. A major zone of de-slating has been created on the outer side due to this sub-vertical crack and is being monitored using mechanical demag.

CAVE 7: All structures in the outer 3-5m part of the cave have collapsed. The crown of cave is supported by four square shaped pillars (all of modern construction). A large portion of the crown to the right has perished along a unit contact, exposing casts of ropy structure. The crown of the cave bears numerous cracks, some of which are parallel to unit contacts. The category V crack seen on the crown in the hall is traceable on the floor of left hall of cave 6, stacked above cave 7.

CAVE 8: The third cell of the cave has a major crack on its crown and walls. In the outer hall a zone of de-slating has been created due to displacement along a crack developed along unit contact.

CAVE 9: A part of the facade above the chaitya motif of this cave is broken.

Cave No. 10: Entrance of this cave is in dilapidated condition. The overhang is traversed by a westerly dipping crack and unit contact. Seepage is observed at three places from the overhang in the form of droplets. Some of the rafters are damaged. The basalt on the lower deck of the outer portions of the verandahs and cells is relatively more weathered. In the cell on the left verandah some part of the crown has collapsed along a unit contact and the remaining portion is in the process of separation. The left verandah of the upper deck has a highly fractured zone in the crown and copious amount of seepage is noticed here. In the two cells on the right, both extensive weathering and seepage is observed.

Cave 11: The front wall serving as entrance has almost entirely perished. On the left wall of the courtyard is an L shaped cell in which numerous cracks can be seen. On the outer side chunks of rock have fallen. The lower deck of cave 11 consists of a long verandah having eight large sized and square shaped pillars. The verandah opens into a shrine in the central part. The crown of the verandah contains numerous category I cracks. Minor fractures are present on the crown of middle deck. The upper deck's inner verandah also has minor cracks.

Cave 12: A cell situated at a height of 5m on the southern wall of the courtyard is in a dilapidated condition. The façade of the top deck is marred by rock fall. On the right side the collapse of the façade/overhang is along a highly fractured zone through which water seeps in the form of a continuous drip. At the landing between the middle and upper decks, seepage is seen from the crown of the staircase. Seepage is also seen in the cell on the southern side of the cave at the landing between the lower and middle decks.

Cave 13: The outer structures of the cave appear to have been destroyed. The right side of the entrance is somewhat intact while the left side is broken. A few cracks of category III are seen on the crown of

the cave. The floor of the cave is covered by residual soil attesting to grade VI of weathering. Seepage noted is in the form of moist patches on the inner side of the front wall on the left. The unit contact serves as the conduit for surface run-off to seep inside.

Cave 14: The outer 4-6 m deep part of the cave has perished. Cracks of categories I to III and trace of squeeze up structure are seen on the crown. Seepage of water in the cave is restricted to the outer beam. The façade of cave 14 can be divided into 3 zones. The lowermost zones just above the crown of the cave consist of moderately weathered basalt. The middle part shows development of negative slope due to differential weathering along a highly fractured zone. Seepage is observed through the fractured zone due to infiltration from the top (where the fractured zone crops up). This is overlain by moderately weathered basalt. On the roof of the cave, water from a nala is directed to the side of the cave by a channel, which is blocked at the end creating damming effect thus leading to seepage over the façade.

Cave 15: The basalt in the crown of 'mandapa' is moderately weathered with flaking at places. There are two cells on either side of the walls of the courtyard. The crown of cell to the left of the 'mandap' has fractures through which seepage is taking place. The cell on the right has almost entirely perished. The crown of the cell situated above the courtyard is highly fractured and at a few places the rock has collapsed. The facade of this double decked cave is marred by rock collapse and weathering. The highly fractured zone cuts across the façade. Minor cracks, traces of squeeze up structures and geodes are seen on the lower deck. The upper deck has seepage zones and moist patches near the 2nd pillar of the 5th beam.

Cave 16: The sculptures on the west-facing wall on either side of the entrance of this finest monument in India appear to have suffered more from weathering due to westerly winds and exposure to sun. The crown of Kailash temple shows two fractures of category V. The bridge connecting the right verandah of Kailash temple to the second deck of Pad Lanka has collapsed. The cracks seen in the crown of the right verandah are probably related to the collapse of the bridge. The cracks have divided the crown into three parts. In the left verandah and the front verandah, minor category I fractures are seen.

The pathway surrounding the Kailash, which has been cut into the scarp is known as the Parikrama. It is a narrow verandah like excavation supported by numerous pillars on three sides and recessed into the scarp. A portion of the overhang has collapsed along a unit contact on the right side. Another square shaped block at the right corner has detached and is shifted by a few millimeters. On the left corner a portion of the overhang has also collapsed and some detached portions are on the verge of collapse.

Numerous fractures can be seen on the crown of first (bottom) deck of 'Pad Lanka', a four decked complex. At the junction of two pillars, constructed to support the crown on the side of the stairway of the first deck, there are small gaps and the load is supported at only one or two points. These gaps should be properly packed to ensure even distribution of load. Extensive weathering has taken place along the unit contact in the third deck of 'Pad Lanka' where heavy seepage is reported. Apart from this, parts of the crown have collapsed along unit contact. At a few places some portions of the crown are precariously balanced. Four pillars having double arched beams support the weight of the overlying

rock mass. All the four beams have developed cracks that are vertical and extend up to the unit contact above. The caves to the left side of the cave 16 and situated at a higher level are in a dilapidated condition due to general neglect.

CAVE 17: Evidence of rock fall and heavy seepage are observed in the left side cell. A masonry column has been constructed to prevent rock fall. The rock mass in the cell is highly weathered. The facade is slightly weathered and shows open cracks from which seepage is observed. The pillars and roof need treatment to avoid any further damage. The pillar present on left side of courtyard is highly damaged. The rock inside the hall is fresh and unweathered. Sculptures present on left and right wall near the entrance of the shrine are damaged.

CAVE 18: Facade of the cave is in broken condition. A quartz vein is seen in the left side, front wall and column. Crown of hall shows indication of seepage. The rock of central hall is fresh and unweathered.

CAVE 19: The front wall that supports the load of rock has developed major fractures and the facade is in dilapidated condition. Central hall is supported by a row of rectangular shaped columns in which the first row of columns has been completely destroyed the 1st column to the left has developed major fractures and is highly weathered. The 2nd column to the left side and first two columns on the right are half constructed with cement concrete. Number of fracture planes / joint planes are present on the crown of hall. Seepage inside the cave is due to infiltration from the drainage channel situated on the left side near the entrance of the cave. Front portion of the crown of hall is highly weathered. Signature of rock fall is evident.

CAVE 20: Seepage is observed from a vertical crack in the verandah and facade. The only sculpture on front wall to the left of courtyard has lost its sharpness due to weathering and is damaged due to cracks. Basal 0.3m portion of cave is slightly weathered as compared to the rest of unweathered portion of hall and verandah.

CAVE 21: Encrustation of calcium carbonate is observed in the corners of central hall. The rock mass of chabutra (Nandi portion) is slightly weathered and the sculptures have lost their sharpness and are partly damaged because of weathering. Seepage in the form of continuous dripping is noticed from the crown portion on the right and the pillared porch in the central hall.

CAVE 22: A few category II and III fractures are observed on the left and right pillared porch of the central hall. The left aisle of the central hall has seepage on the front wall side. Seepage is also noticed on the right cell of the central hall along a vertical crack in the crown portion and from a horizontal joint above the left cell in the courtyard. Surfaces above the left cell need to be treated.

CAVE 23: The cells, which are in rows, indicate a stable roof without any fractures whereas the cell on the extreme left is in a dilapidated condition. The two pillars of the cell need immediate treatment. Wall between 1st and 2nd right shrine is having a large hole. Seepage in the form of dripping water is noticed from the left corner of the shrine cell. Rock mass of this cell is moderately weathered.

CAVE 24 and 24A: These two caves are joined with each other by a common wall, and consists of a verandah and a shrine. The crown of verandah has fracture / valley relief joint through which seepage



is noticed. This fracture needs immediate treatment. Seepage is noticed in the form of continuous dripping of water from right unfinished cell.

CAVE 25: All the six pillars in the courtyard have been destroyed. The overhang portion in courtyard is unsupported and has developed many cracks. The water tank outside the cave towards right should be covered / filled with concrete to prevent any accident. Seepage is mainly from the crown of verandah. A highly fractured and jointed portion is noticed in the left and right side of facade where rock mass is likely to fall in the near future. The Nandi in the courtyard is completely destroyed and only the basal portion is preserved.

CAVE 26: Highly fractured and jointed zone is observed on right side of the facade of cave above the water tank, which may lead to rock fall. Rock inside the cave is unweathered. Right side front wall of central hall indicates plastering of wall, which has been peeled off from most of the places.

CAVE 27: The facade of this cave is stable except towards right side where small jointed, and fractured portion is to be removed and treated. The crown of central hall in front of left cell shows weathered unit contact with fractures from which seepage is noticed. Seepage is also noticed from facade of cave in the form of droplets. Rock inside the cave is slightly weathered.

CAVE 28: Horizontal joints along unit contacts are open and require treatment. The floor of cave is uneven rocky surface.

CAVE 29: The rock mass of overburden of four cells on the left hand side, outside the courtyard has developed open joints which has to be removed or slope stability measures have to be taken to prevent damage to the cells in case of rock fall. The Central hall consists of two rows of rectangular pillars and three aisles each on left and right side. Distress cracks are observed in some of the pillars. Dripping of water is noticed in the facade of open passage of cave. Locally waterlogging conditions are observed in a narrow open portion in front of porch. In the porch there are six pillars in a row which are in a highly damaged condition. Rock fall in the form of rolled boulders is noticed in the open narrow passage.

CAVE 30: The left porch and peripheral portion of the cave has local water logging conditions. Near entrance, the cave's right side has developed a horizontal fracture with open joint. The blocks may get dislodged anytime where the rock is highly weathered and vesicular in nature. Seepage is noticed from a category V fracture present in the crown of entrance and left corner of central hall. Major damage is seen towards outer left portion where a part of facade has fallen. Pillars inside the cave are moderately weathered at the base. Sculptures on outside walls of cave are moderately weathered and damaged due to micro fractures and weathering. Chemical treatment is required for cleaning the weathered and moss-covered portion outside the cave.

CAVE 31: Two major fractures of category V run across the hall through which seepage is noticed. Facade of cave consists of highly jointed rock mass that requires treatment. Rock is moderately weathered outside the cave. Relief joint observed on a sloping ground in facade and above the cave lead the infiltrated water from top weathered zone and soil cover, in to the cave.

CAVE 32: A fracture of category V facilitating seepage is noticed on the crown of the 1st left cell. Seepage is noticed from a hole in the crown near 1st right pillar. Right side 1st cell in the courtyard is an incomplete excavation where a fracture of category V facilitating seepage is observed. A crack of category IV is observed in the crown portion of central hall. Seepage is observed inside the cell adjacent to the hall of upper deck. Facade of right side complex is weathered and fractured where seepage is noticed. In left complex, a crack of category III facilitating seepage is observed.

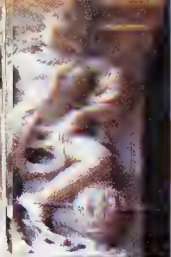
CAVE 32B: Fractures of category V facilitating seepage is noticed on both left and right side of the hall.

CAVE 33: In the central hall of ground floor a major quartz-jasper-flint vein is observed. A number of category III to V cracks facilitating seepage are observed on the crown of central hall. Crack of category V is noticed in the corner of right aisle of upper deck where seepage is noticed.

CAVE 34: Wall between caves 33 and 34 is broken. Facade is highly jointed and has developed many cracks. Rainwater accumulates in the right corner near entrance where water tank is present. Crown of central hall indicates cracks of category V. The rock is slightly weathered.

Seepage, present in some of the caves at Ellora, is mostly restricted to cave frontals / portals. The sources for the seepage are immediately above the caves or in adjacent areas. The fact that the interior walls of many caves (particularly the back wall) are not damp proves the facts that the water percolating down is limited the interior rock mass is generally impervious and the source of water is not from far behind the caves in the plateau. The factors contributing to seepage in the caves include the fractured facades / portals with a number of weak planes (e.g. caves 1 to 5), thin rock cover (e.g. caves 10, 19, 23, 24, etc.), and presence of soil above the caves which absorb a lot of water. The water is released slowly, feeding the successive lower zones to the interconnected network of weak planes in the portals (cave 1 to 5) or any concealed network present in the rock below the soil cover. The later causes seepage in the caves only if the rock cover is not thick or has joints / weak planes that persist with depth coupled with poor performance of the existing drains. The contribution of nala water for the seepages is extremely limited. However, a small nala above cave 2 was observed to feed a concealed crack during a heavy downpour. Interestingly, the drain made above caves 1 to 4 hardly receives any water during the downpour. As the cave slopes are situated between the plateau and plain country, all the water from higher elevation gravitates towards the plains. Most of it goes as surface runoff through the nalas but insignificant part of it gets trapped in the weathered and fractured zones of slopes and in the soil that overlie them with relatively flatter gradient. It is this water that causes seepage.

Geoseismic studies indicate that the area falls in Zone-I of the Seismic zonation map of India. This attributes the zone a 20% probability of earthquakes upto magnitude of 6 on the Richter scale. From a seismic perspective, the area has been divided into two zones. **Zone I:** Consisting of recent alluvial fill and thin soil cover, with low slopes of 2° - 5° and having shear wave velocity (V_s) of ~ 1 km/sec with Seismic Rigidity (SR) ranging from 3.4 - 5.04. **Zone II:** Consisting of amygdular (and vesicular) and dense basalt, with V_s 2.6 - 2.8 km sec. The slope is of the order of $>40\%$ with Seismic Rigidity (SR) ranging from 13.05 - 14.40.



Seismic Risk Assessment studies indicate that the area has low to moderate vulnerability to seismicity with a probable magnitude of 6 on the Richter scale and seismic risk of 40% in 50 years. In Cave no. 12, a 1.20m to 1.50m wide fracture zone trending N 10° W - S 10° E with 45° dip towards S 80° W is encountered on the southeastern face of the cave entrance. A waterfall is observed, originating from the hill slope above the cave 2. Cascading waterfall near Cave no. 29, originates from the hill slope above the cave and daylights near the base of the cave. These zones can be vulnerable in the event of a major seismic activity. Seismological and geological data indicate that the area falls in low to moderately vulnerable seismic activity zone.

The results of geophysical surveys carried out using shallow refraction seismic methods to study hidden moisture rich zones, joints, cracks, fractures controlling the seepage of water and weathered rock show that the area above caves 1 to 5 has high resistivity and a conductive zone is present just above the caves 3 and 4. Some fractures are also indicated in the area. The resistivity data in the area above the caves 6 to 22 show high and low resistivity zones. The zone above the caves 17 to 22 has shown two distinct conductive zones. The results of post monsoon resistivity studies are similar to pre monsoon and are more defined. Seismic refraction surveys indicated the presence of a moderate velocity and a low velocity layer at depth. The third layer again shows a higher velocity suggesting the presence of a fracture in the region.

Environmental studies on selected environmental parameters such as, micrometeorology, ambient air quality, water quality, noise monitoring, ambient temperature and humidity in the caves and visitor's impact on cave environment, land use, land cover, soil studies, and impact of developmental activities revealed that:

1. Prevalent wind direction during the month of January to March was northerly and northwesterly. During the months of April to September the wind direction was westerly and during the month of October the wind direction was bi-modal and the prevalent directions were easterly and northeasterly. During the months of November and December the prevalent wind directions were northerly and north- westerly. During the winter months the mercury touched a low of 10°C whereas it has reached a high of 44.1°C in summer months. During the year 1999 the area received only 512 mm of rainfall during the monsoon season, which is much lower than the average annual rainfall. During winter the humidity varied from 24% to 89% and during summer and monsoon the variation was between 13% and 99% and from 31.4% to 99% respectively.
2. The Flora of the area represents tropical deciduous scrub forest, which is in a state of degradation to dry deciduous forest and is continued to the areas with poor soil and steep slopes. The species exhibit various stages of transition from tree forests to scrub forests.
3. In cave 15, SPM and RPM values are above the permissible limits of 100 and 75 mgm/m³ during the months of March and April. Near cave 32, SPM and RPM values are less than those at cave 16 and 15.



4. Chemical analysis of 25 samples of water for 23 parameters collected during two seasons i.e. winter and summer and seepage water in the rainy season, show that the major mineral constituents and toxic metals are well within the permissible limits as assessed against IS 2296 (Class 'A' water). Storage tank water of cave 34 during winter and summer show pH values of 5.90 and 3.60, which indicate that it is slightly acidic in nature.
5. Cave nos. 2, 10, 8, 16 are the most affected by noise pollution as compared to the caves which are open i.e. 1, 6, 12 and 32.
6. The seismic noise levels in the higher frequency range (8 to 20 Hz) for all the caves are attributed to vehicle generated seismic noise. Maximum noise levels were recorded at cave 10 and minimum at cave 32. The main noise source was identified as the heavy vehicular traffic on Dhule - Aurangabad State highway.
7. Bats are nesting in cave 5, 12, 16, 19, 25, 29, 30 and 32 and pose threat to the sculptures by leaving black and white patches on the walls.
8. Temperature and humidity were recorded in all the 34 caves at Ellora. Analyseis of data on selected caves including cave 1, 2, 5, 6, 10, 12, 14, 16, 17, 19, 19 B, 21, 25, 29, 30, 32 (upper deck) and 34 indicate that the host rock of caves having higher humidity values are comparatively more weathered.

RECOMMENDATIONS

Based on the multidisciplinary geoscientific studies carried out at Ellora caves the following remedial measures are suggested:

Slope Protection

The suggested protection measures are shotcrete (25 – 50mm), reinforced shotcrete (50 – 100 mm, with wire mesh), rock bolts and anchors (20-25 mm diameter, tensioned, grouted) ranging from 1 – 8 m in length. Zone/sector-wise treatment measures are suggested on the slope protection maps. About 400 number of rock bolts (<2m length & 25mm dia.) having total length of 800m and 115 number of rock bolts (2-6m long & 25mm dia.) of about 750m lengths are to be fixed. The slope needs to be treated with plain shotcrete (25-50mm thick) in about 19300 sq. m. area and reinforced shotcrete (100mm thick with chain link/mesh) in 4050 sq. m. area. Finer details of these damages and remedial designs are to be worked out at the time of execution. For example, if rock bolting and shotcreting are suggested to strengthen a cave facade or a degraded slope, the exact sites for fixation of these rock bolts, their length, direction and angle of fixing and the thickness of shotcreting are to be decided by careful detailed examination at the time of execution.

Because potential seismogenic zones towards the north and south of the area and the possibility of Stable Continental Region (SCR) earthquake striking hitherto unknown areas, “a systematic monitoring of earthquake activity by seismic network is essential”.

Cave Protection and Surface Water Management

The generalised suggested treatment measures are as follows:

1. Reinforced shotcrete with rock bolts above caves (at suggested spots) and selective shotcrete above portals and edges. Provision of windows (unshotcreted areas) and drainage arrangement along unit contact, at identified places.
2. Bolting of loose block in the crown (e.g. cave 1).
3. Improvement of the existing drains by: (a) fresh lining, (b) excavating them to the bedrock level wherever necessary, (c) increasing gradient, (d) widening the narrower ones and (e) providing weep holes on the scarp / wall side.
4. Construct of longitudinal drains on the slope above caves as suggested.
5. Strengthening the roofs of some caves (10, 16, 18 etc) with reinforced shotcrete and rock bolts.
6. Scraping of the top surface upto about 20m from the edge of the portal prior to shotcrete to take care of seepage. Construction of new drain immediately above the shotcrete zone. The drains are to be located in bedrock.
7. Filling of potholes and pools upto the waterfall in the nala above cave 5 and lining of central 2-3m zone of perennial flow channel. Provision of iron barrier across the nala at about 20m from the edge to arrest rolling boulders.
8. Installation of load cells in caves 1,7 & 25 to monitor unsupported spans at the portal.
9. Involving a Structural engineer to assess the implications of the transverse cracks at cave 6 and 17 and to design suitable remedial measures.
10. Big trees within the sloping limits of cave area are to be uprooted and removed or trimmed so that the roots do not penetrate into the rock and crack it.
11. Fresh shotcreting in the intercave zones and existing deteriorated gunited surface after scrapping.
12. Strengthening of the weathered / distressed pillars by epoxy / polymer grouting, casing and / or microstiching.
13. Monitoring of the cracks.
14. Provision of concrete / shotcrete over the crown area with inadequate rock cover for protection against seepage.

Environmental Protection Measures

Based on the observations already listed above and keeping in view the sanctity and aesthetics of the monuments the following measures are suggested.

1. Remedial measures such as shifting of present parking place for tourist vehicles to a place at least 1/2 km away from the caves, preferably to the left side of Aurangabad – Ellora road and tarring



it, planting tall growing trees by the side of road leading to caves to act as natural receptors to the particulate matter, removal of grass in the caves confines and ban on grazing, turffing / paving or developing a garden and afforestation of the area are suggested to improve the air quality of Ellora caves area. To improve air quality inside the caves, all the entry points should be covered with wire mesh, poly grass, astroturf etc. for suitable lengths. Vacuum cleaning twice a week within the caves, ban on storing building material such as cement and chemicals in the caves should be implemented.

2. Noise levels in the parking area are too high during peak hours which are above the prescribed limits for sensitive zones, hence the area may be declared silence zone. To reduce ground vibrations, entry of heavy vehicles up to the gate of cave 32 should be banned. To keep the noise levels within tolerable range, people should be cautioned by proper guidance and suitable and sufficient display of posters/ pamphlets at entry points especially at cave 10, 16 (main temple), 32 (top deck) and 34 (top deck). The entry of vehicles up to the cave 10 should be stopped.
3. The state highway passing through Ellora village needs to be relocated with a diversion from Palaswadi on Dhule-Aurangabad road via Kasabkheda to reduce seismic noise.
4. The water stored in storage tank of caves 10, 11, 12, 17 and 27 should be periodically treated and should be covered. Safe potable water may be made available at cave by extending the existing water supply line and water vending machines may be installed at 5 to 6 places. Use of storage tank water for drinking purpose should be stopped.
5. The entire area of cave from 1 to 34 should be suitably fenced. Entry of stray animals should be banned. Foot track on the left side of cave 16 leading to the top of cave 16 is in bad shape and should be remade. A foot track leading to cave 25 from cave 24 is also in bad shape and it should be properly guarded by railing. Railing by the sides of opening of cave 16 on the top on 3 sides should be made for public safety. Foot track from the left side of Khultabad to Cave 16 should be guarded by the railing on the roof - top of cave 15 or from the left side of foot track near cave 15. Existing railing at Chikni Lanka (cave 16) should be extended up to the next wall.. Stairs of cave 16 should be repaired and lighted properly. Similar measures should be taken for the stairs of Chikni Lanka.
6. A toilet near caves 1, 21 and 32 on the lower valley slopes may be constructed with proper and effective waste disposal system. Proper garbage collection and its disposal away from the caves' environ should be brought into practice and enforced.
7. A R.C.C. structure constructed for office between cave 16, and 15 should be removed.
8. To minimize humidity fluctuations inside the caves, possibility of installing humidity control equipment should be explored.
9. To overcome the bat menace, the cave entries should be covered with doors/wire mesh after driving off the bats or sufficient lighting arrangement inside the caves should be done.
10. Proper garbage collection and its disposal are recommended.

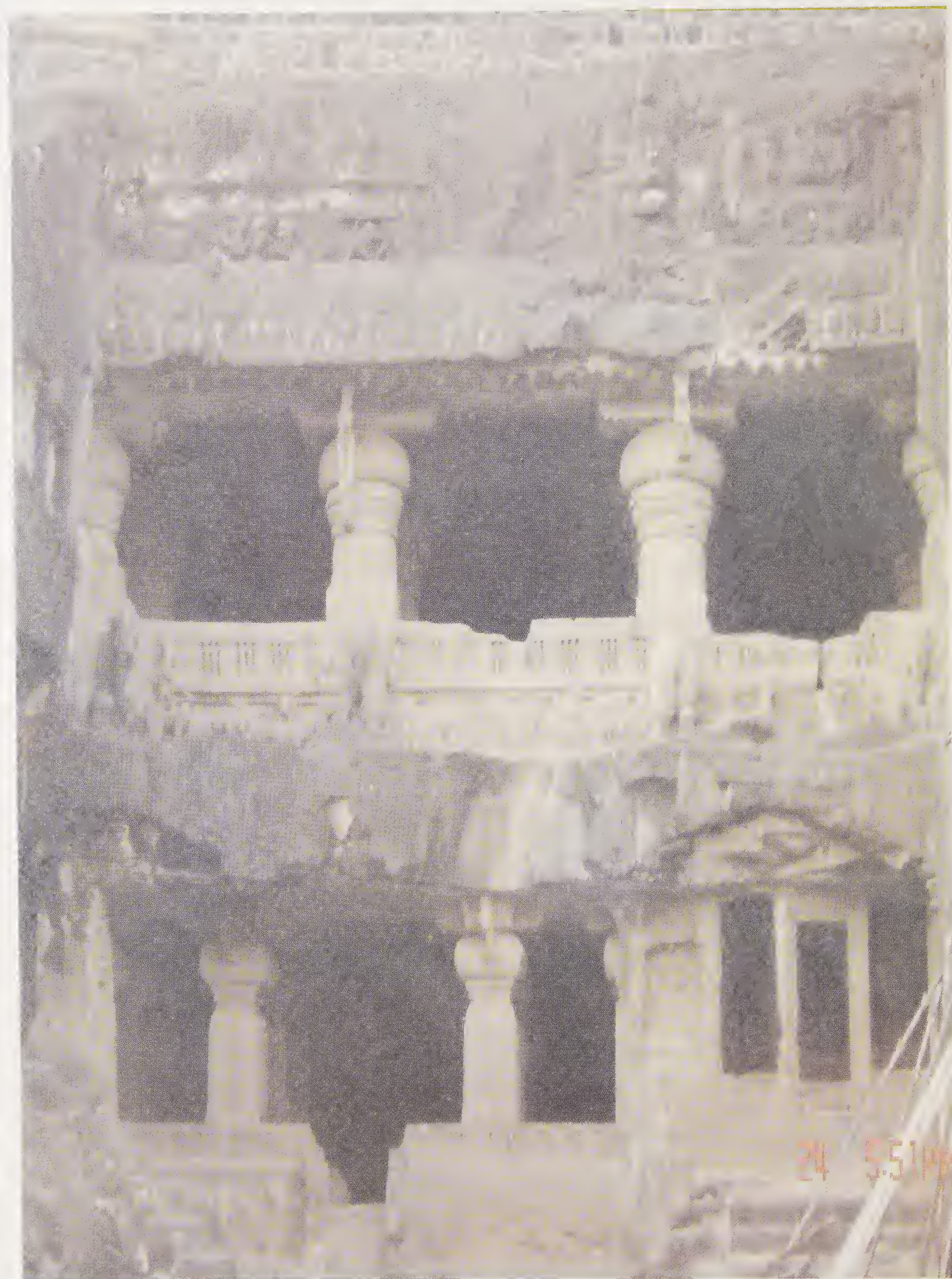


Crucial Factors Governing Efficacy of Remedial Measures

1. Agency selected for execution of works should have proven track record of excellence and experience in carrying out such works.
2. Materials used should be of very high quality. Steel rods used for rock bolting must have very high tensile strength and should be non-corrosive.
3. All the remedial measures should be executed under the constant guidance of engineering geologists from the GSI and civil engineers from the identified agency and the ASI.
4. Deployment of medium to heavy machinery and drilling of the rock mass at several places is inevitable and all operations are to be carried out ensuring the safety of the caves.
5. The remedial measures involving shotcreting and rock bolting are being advised for the cave monuments for the first time. Hence, the amenability of the rock mass to accept these measures may have to be evaluated before launching the operations on a full swing. The remedial measures can be initiated in caves of lesser importance from an archaeological perspective but requiring urgent treatment and gradually extended to other important caves based on review.
6. Sufficient precautions should be taken to minimise ground vibrations, noise levels and SPM levels during implementation of the geotechnical measures.
7. Closure of caves to the public (at least partially) during execution of works.



Overview



- 1 The cave temples of Ellora represented by elaborate carvings of gods and goddesses are the product of three religious faiths viz., Buddhism, Jainism and Hinduism. Each system has its individual style of architecture and these are also showcased at Ellora. Caves 1 to 12 are Buddhist, caves 13 to 29 are Brahmanical (Hindu) and 30 to 34 are Jain caves. Cave 16, which is known as the 'Kailash Temple', is the largest of all Ellora excavations and is a classic example of rock cut architecture at its best. Approximately 3,00,000 cubic feet of rock has been excavated to carve out this cave.
- 2 The natural processes of weathering alongwith scarp retreat and biotic interference have had a serious and deleterious impact on the sculptures and paintings in the caves and its environs. Unstable slopes and seepage are the two major causes of concern while applying conservation methods.
- 3 Slope stability problems at Ellora are confined to the cave portals and the adjacent inter cave slopes that bound them. The cave interiors are relatively stable. The presence of four sets of joints, three vertical and the fourth, a steeply dipping set of relief joints along with the fracture zone and cooling cracks, have accentuated weathering and rendered the cave facades and certain slope segments weak. Wherever this fracture zone has intersected the cave openings the outer portion of the caves has collapsed as seen in caves 1- 4, 13 and 14. The relief joints with progressive under cutting of toe have played a major role in the retreat of the slope face by about 5m.
- 4 Seepage of water is restricted to the outer 2-3m portion of the caves. Surface runoff flowing down the slope and from soil and scree zones reaches the cave frontal/façade and permeates into the cracks causing seepage. Some seepage is because of surface water roll back due to surface tension.
- 5 As per the request of the Archaeological Survey of India, the Geological Survey of India undertook a program of geoscientific studies comprising topographic survey and geological mapping of 0.52 sq. km. area, geophysical surveys, geotechnical studies within and outside the caves, terrestrial stereo-photographic studies of vulnerable slopes, seismic risk assessment by micro earthquake studies and environmental impact assessment of the caves and their surroundings.
- 6 **Geomorphic analysis** of an area of 100 sq. km in parts of Survey of India sheet no. 46 P/4 was carried out based on digital image processing, aerial photo studies and limited field checks.
- 7 The area under study forms the eastern valley margin of **Shivna sub-basin of Godavari basin** and is marked by steeply rising N-S trending plateau popularly known as *Maismal Plateau* in the east and Shivna plains in the west. The southeastern part of the *Maismal Plateau* is dissected and forms the northern valley margin of Purna sub-basin of Godavari Main Basin.

- 8 Landforms around Ellora area show a number of plateau surfaces over Deccan Trap flows with a maximum relief of 800m and a minimum of 550m. The geomorphic units seen are alluvial plains, undulating plains, colluvial plains, scarp faces, plateau surface remnants, rugged slope zones, plateau plains, mesa, and linear bodies.
- 9 Lineament fabric of the area exhibits four major sets of lineaments in NE-SW, NW-SE, N-S and E-W directions. Intersections of these lineaments are observed as prominent scarps, linear ridges, narrow valleys with high angled scarps and rectilinear drainage. Entrenchment, sharp turns, meanders, waterfalls and development of rapids along the stream courses are associated with these lineaments. The NE-SW trending lineaments are the oldest while those along east- west direction are the youngest.
- 10 Badland development with rills and gullies as seen to the north and south of Ellora, presence of waterfalls along streams like Jogeshwari nala coupled with steepness and straightness of the scarp are suggestive of tectonic disturbance. As a result, minor slips/ displacement/fault are noticed in some of the caves. This possible fault is intersected by a roughly east-west trending lineament passing through the hills. Alignment of the gaps across spurs/ ridges, extending towards SE from 846m peak and presence of spring point to another possible fault/fracture trending in NE-SW.
- 11 Based on the quantitative estimates of terrain factor such as altitude, relief, average slope etc., two broad genetic classes have been distinguished:(a) Forms of extrusive origin comprising of linear ridges, valleys, plateaus, slopes/scarps and planation surfaces. (b) Forms of fluvial origins comprising of undifferentiated flood plains.
- 12 **Relief pattern:** Deccan Trap basalts show persistent flatness throughout the area with gentle to very gentle gradient towards north, dissected by steep valleys/slopes separating two flat surfaces. The area has undergone three stages of peneplanation and has given rise to three planation surfaces. They are E_3 planation surface, E_2 planation surface (This surface is popularly known as Maismal Plateau) and E_1 planation surface; the depositional surface and T_1 and T_0 Terraces.
- 13 Scarps: A prominent scarp of about 160m between 640m and 800m is seen along the N-S trending, eastern valley margin of Shivna river. The slopes in the scarps are predominantly steep with intermittent moderate and at places precipitous, thereby giving rise to small flats and overhangs respectively. This scarp is further sub-divided into upper scarp $S_{1(a)}$ and lower scarp $S_{1(b)}$.
- 14 Slope pattern of the area can broadly be divided into gentle to moderate slopes over plateau and terraces and steep to very steep precipitous slopes forming scarps and overhangs.
- 15 **Drainage Pattern:** A distinctive N-S trending water divide exists between Shivna and

Purna sub-basins. The Shivna and Purna rivers are the fourth order consequent perennial streams. Secondary drainage pattern in the area is mostly subdendritic and sub-parallel. First order and second order streams exhibit trellis pattern. Streams originating from E_3 and at places from E_2 surfaces show radial drainage pattern. East of the water divide, the streams show higher sinuosity, sharp turns and meanders constituting rectangular and sub parallel patterns.

- 16 The Ellora caves area exposes the Upper Ratangarh Formation comprising seven Deccan Trap basaltic flows of which five are of compound pahoehoe type and two are Aa type of flows. The topmost flow is a megacryst flow, which is a regional marker flow in the area.
- 17 **Topographic surveys** of an area 0.52 sq. km between latitudes $20^{\circ} 01' 10''$ and $20^{\circ} 02' 00''$ N and longitudes $75^{\circ} 10' 40''$ and $75^{\circ} 10' 55''$ E falling in parts of Survey of India sheet No. 46 P/4 was carried out on RF1: 500 with 1 m contour interval.
- 18 The entire area was divided in 52 small well-conditioned triangles and Triangulation stations (survey) were established. Base line was laid between stations T0 and T1. The distance between the two stations was taken as base for side calculations. The magnetic bearing of line T0-T1 was recorded using prismatic compass. All angles were measured using micro optic theodolite. Co-ordinates of apex of triangle were calculated with respect to station number T0.
- 19 For determining reduced levels of the triangulation stations, physical leveling using tilting level was carried out by carrying the recorded level of 605.70 m of the reference pillar (of Survey of India) in front of office of Archeological Survey of India, Ellora caves.
- 20 Radial shots were taken from survey stations established in the area by tachometric method using micro-optic theodolite and graduated/levelling staff. Reduced levels of individual spots were calculated tachometrically and these were plotted on RF 1:500 and contours were drawn at 1m contour interval by interpolation method.
- 21 Geological observation points were taken with respect to survey stations. These were plotted on topographic map on RF 1:500. Geological contacts were interpolated / inferred between two observation points.
- 22 Cave centerline was laid using steel tape and micro-optic theodolite for each cave. These lines were connected with triangulation stations. Centerline points outside the caves were serially numbered.
- 23 Different topographic features were plotted using standard colour and symbols as adopted by "Survey of India" for preparation of toposheet. The data were later digitised on AutoCAD 14 and Auto CAD 2000.

- 24 Geomorphological analysis of an area of about 0.52 Sq. Km around Ellora caves was carried out on RF 1:500. Different landforms were identified.
- 25 **Surfaces:** Two planation surfaces have been recognised in the area. These are the planation surface E_1 and planation surface $E_{1(a)}$ and a depositional surface, terrace (T_0).
- 26 Other landforms include entrenched valley, rapids, potholes and thalwage.
- 27 An area of about 0.52 sq. km around Ellora caves was geologically mapped on RF 1:500. Geological observation points were marked on the ground and their altitudes and bearings were recorded using micro-optic theodolite. These points were later transferred to topo base map of the area mapped.
- 28 The Ellora caves area proper is occupied by two basaltic flows of the **Upper Ratangarh Formation**. The flows are of compound pahoehoe type with well-developed basal pipe vesicles, pahoehoe toes and ropy surface.
- 29 **FLOW NO-I:** This is a compound pahoehoe flow, its thickness ranging from 50-60m. It consists of 15-18 units, with individual unit thickness varying from 2 to 6m. The pahoehoe unit comprises a top vesicular zone, the middle massive part with or without widely spaced vesicles and a thin bottom vesicular zone with bifurcated basal pipe vesicles. The top surface generally shows a thin reddened crust and at many places ropy structure. All the caves in Ellora area are carved within the lower units (1-10) of this flow.
- 30 **FLOW NO-II:** This is also a compound pahoehoe flow with an exposed thickness of about 60m. It consists of 15-18 units with similar unit characters as of flow no. I. Some of the units pinch out while others are added particularly in the central and northern part of the mapped area. The top contact of this flow is not exposed in the area mapped.
- 31 Slopes, surfaces and flats around the Ellora caves are occupied by soils and scree. Different types of soils and scree identified are black cotton soil, inceptisols, transported silty soils, clast supported scree and matrix supported scree.
- 32 Different primary structures observed in the area include polygonal cooling joints, ropy structures, pahoehoe toes, pipe amygdulites, vugs/cavities, lava tunnels, in-crack fillings and squeeze ups. The secondary structures seen in the area include four prominent sets of joints, relief joints and exfoliation joints.
- 33 Petrochemical studies of basalt samples reveal that basalt of the flow units are predominantly quartz normative tholeiites and are more to highly evolved in nature with initial iron enrichment, followed by depletion of MgO. Some flow units though tholeiitic, show marginally higher alkaline nature with their silica content being comparatively low indicating over saturation and probable transitionary nature towards

the alkaline field from the tholeiitic field. The MI versus FI plots indicates middle to late stage of fractionation of magma.

- 34 **Geophysical surveys** were carried out using shallow refraction seismic methods to study hidden moisture rich zones, joints, cracks, fractures etc. controlling the seepage of water and weathering of rock. Regular resistivity studies could not be taken up everywhere in the region in the pre-monsoon period because of the absence problem of soil cover at many places.
- 35 Monsoon rains induce profound changes in seepage by way of saturating pore spaces, joints and micro fractures, recharging the hidden channels, and saturating every concealed conduit in the rock mass. Regular resistivity studies could be conducted in the post-monsoon period when the area above the caves has thin cover of soil, which enabled the electrode penetration at several places.
- 36 A total number of 4 traverses over a cumulative length of 2.5 km were laid in region over the caves.
- 37 Instruments used: TVLF, DDR-2, Signal Enhancing Refraction unit and micro-optic theodolite were used.
- 38 Pre-Monsoon data of resistivity studies carried out in the Ellora caves area by deploying the TVLF unit shows that the area above caves 1 to 5 has high resistivity. A conductive zone has been indicated just above the caves 3 and 4. Some fractures are also indicated in the area. The resistivity data in the area above the caves 6 to 22 show high and low resistivity zones. The zone above the caves 17 to 22 has two distinct conductive zones.
- 39 The results of post-monsoon resistivity studies are similar to pre-monsoon results and are more defined.
- 40 Seismic refraction surveys were carried out along the traverses to map the velocity distortions in the region above the caves. The shallow layer has indicated a moderate velocity and a low velocity layer has been indicated at depth. The third layer again shows a higher velocity, suggesting a fracture in the region
- 41 A broad correlation is seen in the results of the seismic and resistivity surveys.
- 42 **Seismic assessment** studies were carried out to identify the main seismic characteristics of the area, which include review of regional seismicity and major seismogenic lines, microearthquake studies and surface noise survey.
- 43 The lineament fabric of the area shows predominance of E-W and N-S to NNE-SSW trending dykes. Occasional NE-SW trending micro lineaments have also been deciphered. The Upper Godavari fault, a major NW-SE trending and E-W trending Tapi mega-lineament traverse the area.

- 44 Bouger anomaly contour values range from (-40) to (-90) milli gals and have broad NW-SE to ENE-WSW trends, exhibiting parallelism to the Godavari and the Tapi structural trends respectively.
- 45 The main characteristics of seismicity indicate that the area falls in Zone-I of the Seismic Zonation map of India. This attributes the zone a 20% probability of earthquakes upto magnitude of 6 on the Richter scale. The area bounded by Latitudes 19° - 21° N and Longitudes 74° - 76° E has registered a number of earthquakes between the year 1858 and 1993. These are mainly shocks of low to moderate magnitude < 4.3. The Killari earthquake of 30th September 1993 had a magnitude of 6.3 and was located about 200 km south of the cave area. Micro seismic activity has been observed in Gevrai in the south and in Dalwat towards west.
- 46 The Seismic Rigidity (SR) factor of the two basic categories of ground, namely alluvium / soil and basalt found in the area varies from 3.42-5.04 and 13.05 – 14.4 respectively.
- 47 From a seismic perspective, the area can be divided into two zones. Zone I: Consisting of recent alluvial fill and thin soil cover, with low slopes of 2-5°, having shear wave velocity (V_s) of ~ 1 km/sec with Seismic Rigidity (SR) ranging from 3.4-5.04. Zone II: Consisting of amygdular (and vesicular) dense basalt with V_s 2.6 -2.8 km sec. The slope is of the order of >40 % with Seismic Rigidity (SR) ranging from 13.05-14.40.
- 48 By combining all seismological and geological information, the area has been characterized as low to moderately vulnerable to seismic activity. However, considering the potential seismogenic zones towards the north and south of the area and the possibility of Stable Continental Region (SCR) earthquake striking hitherto unknown areas, a systematic monitoring of earthquake activity by seismic network is essential.
- 49 **Micro earthquake** surveys were carried out to monitor the seismic activity and evaluate the seismological status for Ellora area. Micro earthquakes have similar source mechanisms as strong earthquakes but occur more frequently. The frequency of occurrence of earthquakes increases by factor of 10 with decrease in magnitude by one. Hence a large amount of data can be generated in a short period of time employing MEQ surveys. The monitoring of seismic activity in Ellora area was restricted to about one week. Initially the aperture radius for the network was kept at 500 m and later extended to 5 km in the area.
- 50 The MEQ seismometers SS-1 alongwith the analog PS-2 recorder were used for conducting seismic monitoring in Ellora area.
- 51 MEQ sensors along with recorders were established at Ellora in caves 10, 16 and 32 with network aperture radius of about 500 m. Stations were established at cave 32, Kagazpura and Pimpalgaon for setting up larger network with aperture radius of about 5 km.

- 52 Two seismic events were recorded on seismograms in Ellora area during the period from 13-9-99 to 25-9-99.
- 53 MEQ monitoring suggests that as far as events of magnitude greater than 0.5 on the Richter scale are concerned, conspicuous local seismological activity within an area of 100 km radius is absent around Ellora caves. The vibration effect due to the events recorded is not important as far as damage to the monuments is concerned.
- 54 In recent times surface noise from vehicular traffic and tourist inflow has increased in and around the caves. Over a long period, the vibrations induced by human activities may have a deteriorating effect on the caves, sculptures and the paintings even if the noise level is of low magnitude.
- 55 The ground vibrations generated at the cave site were monitored with the help of Micro Earthquake (MEQ) recorders. The MEQ recorders with seismometers were set in the caves 10, 16 and 32.
- 56 The noise levels in the higher frequency range (8 Hz to 20 Hz) for all the caves are attributed to vehicle generated seismic noise.
- 57 Noise levels are inversely proportional to the distance from state highway. Beyond distance of 1500m these are reduced to very low levels.
- 58 **The state highway passing through Ellora village needs to be relocated with a diversion from Palaswadi on Dhule-Aurangabad road via Kasabkheda.**
- 59 Maximum noise levels were recorded at cave 10 and minimum at cave 32. The main noise source was identified as the heavy vehicular traffic on Dhule- Aurangabad state highway.
- 60 **The tourist vehicles approaching and leaving the parking lot near Cave 16 were also found to generate noise. Parking lot for the tourist vehicles should be shifted from its present location.**
- 61 **Geotechnical** studies were carried out, both inside the caves and in the hill slopes/ scarp slope above and below the caves, with a view to identify the problem areas (seepage zones, unstable slopes, potential zones of deslabling, rock fall and toppling etc,) to identify the causative factors (weathering, process of valley widening) and to suggest selective protection/ treatment measures.
- 62 Slope map for about 0.15 sq. km area has been prepared based on the topographic map and seven categories of slopes have been identified and demarcated.
- 63 Terrestrial stereo-photographic techniques have been used to prepare rock mass distribution and slope protection maps. Charecterisation of rock mass was carried out on the basis of three basic parameters of relative strength, joint volume and relative

weathering. Rock mass distribution maps were prepared based on rock mass characterisation and joint analysis. Analysis of rock mass distribution maps was done to determine selective protection/ treatment measures.

- 64 The rock mass has been characterised on the basis of three basic parameters of relative strength, joint volume/ degree of jointing and relative weathering and divided into various categories along the slope surfaces.
- 65 The presence of four sets of joints, three vertical and a steeply dipping fourth set of relief joints along with the fracture zone and cooling cracks has accentuated weathering and rendered the cave facades and certain slope segments weak. Wherever the fracture zone has intersected the cave openings, outer portions of the caves have collapsed as is evident in caves 1-4, 13 and 14. The relief joints with progressive undercutting of toe have played a major role in the slope retreat by about 5m.
- 66 **The assessment of slope stability in sector I (caves 1– 7) :** The rock mass is of 'Mms' type with local 'Lcm' patches in the flow contact zones. The vertical joints set (J_2 and J_3) and the fracture zone in combination with the J_1 joints have rendered the frontal of caves 1 to 5 unstable and accentuated seepage in the outer 1–2m zone of caves 1,2 and 4. No seepage is seen in caves 5, 6 and 7. The facades of most of these caves have collapsed. **The outer 5-m zone with relief joints/cracks is the causative factor for seepage inside the caves. The nala above cave 5 with large potholes does not contribute to seepage in the caves at present but needs attention to prevent the possibility in the long run.**
- 67 **The assessment of slope stability in sector II (caves 8 -16) :** The rock mass is mostly of *Mms* type with *Lcm* type in the unit contact zone. The presence of relief joints (J_4) alongwith cooling cracks has accentuated weathering of slopes. The seepage in the caves is confined to the outer 1-2 m zone of relief joints. The dense basalt with predominant basal set (J_1) and the flow contacts at the roof level of caves 10 and 16 (side caves) have caused local gravity falls.
- 68 **The assessment of slope stability in sector III (caves 17 – 30) :** The rock mass in general is 'Mms' and 'Mcs' type with patches of 'Lcm'. The weathering (Grade III/II) is very pronounced in the caves and outer slopes. The vertical sets of joints (J_2 and J_3) in combination with the basal set (J_1) have caused wedge failures in the frontals of the caves 17, 18 and 21. Prolonged erosion along the unit contact has formed negative/ reverse slopes (caves 19, 20, 21, 25, 26, and 28) that have made the cave frontal slopes critical with overhangs. Accentuated seepage is seen in the outer relief zone of cave 17.
- 69 **The assessment of slope stability in sector IV (caves 31 – 34) :** The rock mass in general is of 'Mms' and 'Mcs' type with few patches of 'Lcm'. The relief joints (J_4) with dips of 50-65° towards SW in the outer zone of 2-5 m have made the slopes critical at

certain locations. The weathering (Grade III and II) is very pronounced in the cave surroundings. Seepage in the outer zone of 2-3 m. with relief joints is very pronounced.

- 70 Slope protection maps were prepared, based on the rock mass distribution, identifying areas requiring specific treatment with means like shotcrete (25-50 mm), reinforced shotcrete, with wire mesh (100 mm thickness), rock bolts, anchors (20-25 mm diameter; grouted, tensioned).
- 71 Details of geology, unit contacts and structural features like joints / cracks etc, occurring on the crown portion of the caves were plotted on RF 1: 50. The points were first transferred from the crown to the ground using a plumb bob. A device was designed and fabricated for transferring the points in high caves using a laser pointer and adjustable tripod.
- 72 A system of grading of these cracks on the basis of hazard potential was devised and all the cracks/ fractures were graded on a scale of 5. The factors, which were taken into consideration during grading, are the length of the crack, its orientation (whether it is parallel to the scarp or transverse to it), the aperture, healing, filling, depth, roughness and inclination (shallower the angle greater the hazard). In this scale, category 1 represents stable / hairline fractures or linear features without any opening with the least hazard potential. At the other end of the scale, category 5 represents unstable/open cracks/ sections where treatment may be required. Category 5 represents highest hazard potential.
- 73 CAVE 1 is a simple 'vihara' with eight cells. Structures in the outer 9 m have been destroyed. Above the entrance of the cave weathering has resulted in creation of an overhang. In the overhang, some portions have been dislocated. The façade of cave 1 can be divided in to three zones. The lower one immediately above the crown of the cave and upto the drain shows moderately weathered rock. Biogenic growth in the form of moss and small plants is noted in this zone. Seepage in the form of droplets can be seen from numerous places through the cracks developed in the weathered rock. The second zone extends from the drainage upto the negative slope. The negative slope has developed due to differential weathering in the highly fractured zone. This highly fractured zone forms the conduit for water, which infiltrates to the ground level. The third zone is above the negative slope and forms an overhang. There is no dripping from this zone. Most of the cracks that have developed in the hall of the cave are in the outer half. Near the entrance one small block has started detaching and is likely to fall at any time. Seepage in the cave is restricted to the outer 1-2 m of the hall and the first cell on the right. Treatments suggested include reinforced shotcrete with rock bolts above caves 1 and 2 and selective shotcrete near the top of the edge, provision of windows and drainage at places, scraping of the top surface to expose fresh rock upto a distance of 20m from the edge, followed by shotcreting the surface. Stripping of soil in this zone followed by laying of an impervious layer (geosynthetic or shotcrete)

and later re-laying of the stripped soil with grass cover will adequately take care of the seepage. A drain should be constructed at the upper end of the shotcreted zone, which should be embedded in bedrock and bolting of the loose blocks on the crown of cave 1 is recommended. Load tests must be carried out in cave 1 in view of the large unsupported spans.

- 74 CAVE 2 appears to be a 'Chaitya' and has an open verandah with a small over hanging roof, without support. In the verandah, seepage is seen through a crack on the right side. The façade of cave 2 can be divided into three zones. The lower zone consists of the plastered portion. Above this, the weathered rock forms the second zone. This zone is fed by rainwater percolating down the highly fractured zone and water from the drain, in turn feeds the weathered rock concealed under plaster in the lower zone. The upper zone forms a slight overhang at places and does not show any seepage. Only minor fractures are present in the cave. Seepage in cave 2 is seen in the front aisle at the contact of the wall and crown through a crack above the window. The seepage is in the form of droplets. Treatment suggested includes reinforced shotcreting with rock bolts above caves 1 and 2 and selective shotcreting near the top of edge with provision of windows and drainage at places, scraping of the top surface to expose fresh rock upto a distance of 20m from the edge followed by shotcreting the surface, stripping of soil in this zone followed by laying of an impervious layer (geosynthetic or shotcrete) and relaying of the stripped soil with grass cover will adequately take care of the seepage. A drain should be constructed at the upper end of the shotcreted zone embedded in bedrock. Polymer filling of the cavity in the right gallery.
- 75 CAVE 3 is a 'Vihara' and consists of a central hall, four aisles and 12 cells and a shrine. The outer part consisting of a verandah has been destroyed. Above the cave an overhanging portion has developed and some portions of the overhang have been dislodged. The rock above the cave appears to be extensively weathered. A portion of the crown of the front aisle has collapsed. One major crack runs across the third cell on right, the right aisle, the beam on the right, the central hall, the left beam and the left aisle. Within the cave the crack is wider towards south and closes towards the north. There are no fractures in the shrine. There is no seepage inside the cave. Some seepage is seen in the form of droplets from the façade. The water appears along a unit contact. The water channel made above cave 5 towards cave 1 appears to contribute to the seepage. The treatment suggested includes reinforced shotcrete with rock bolts above the cave and selective shotcrete near the top of edge with provision of windows and drainage at places, scraping of the top surface to expose fresh rock upto a distance of 20m from the edge, followed by shotcreting the surface, stripping of soil in this zone followed by laying of an impervious layer (geosynthetic or shotcrete) and relaying of the stripped soil with grass cover which will adequately

take care of the seepage. A drain should be constructed at the upper end of the shotcreted zone, which should be embedded in bedrock.

- 76 CAVE 4 is a two-decked cave, the outer 6 – 6.5m of which have collapsed. The original cave must have consisted of an outer verandah, a central hall, an outer chamber and shrine on the lower deck facing west. On the upper deck, the cave probably consisted of a verandah, an antechamber, a shrine with walk away and cells on either extremity. What remains now is part of the hall, outer chamber and shrine on the lower deck and a small part of the verandah and outer chamber, half of the shrine and the cell on the eastern sides and part of the walkway are seen on the upper deck. There are numerous cracks on the crown of the lower deck. The roof of the lower deck is about 90 – 95 cm thick. The cracks developed in the walls of the upper deck were repaired by insertion of clamps and grouting with cement mortar. Similarly the floor of the upper deck was extended by about 1-3m using RCC. This additional load has resulted in the development of cracks in the walls of the shrine and the doorway of the walkway and in the walls of the cell on the eastern side (See photographs). Seepage from the façade is through the weathered basalt (showing exfoliation weathering) in the form of droplets. There is no seepage on the lower deck. Seepage on the upper deck is through the weathered zone/ unit contact and is in the form of droplets. On the facade an overhang has been created. In the overhanging portion a few blocks have started to get dislodged. **The treatment suggested includes reinforced shotcrete with rock bolts above cave 4 and selective shotcrete near the top of edge, scraping of the top surface to expose fresh rock upto 20m from the edge, followed by shotcreting the surface, stripping of soil in this zone followed by laying of an impervious layer, (geosynthetic or shotcrete) later followed by relaying of the stripped soil with grass cover which will adequately take care of the seepage. A drain should be constructed at the upper end of the shotcreted zone and should be embedded in bedrock. Two pillars and a beam may have to be constructed on the lower deck to check failure by toppling.**

- 77 CAVE 5 is a large cave and the surviving portion includes a central hall, back aisle, shrine and pillared porches with inner cells on either aisle. Above this cave is a seasonal stream and the flow of water has been regulated with the construction of a cantilever limb. In the front aisle the crown has partially collapsed. The cell on the right has also perished. On the left aisle there is a pillared porch and shrine. Both the pillars of the porch have collapsed. Towards the middle of the left aisle is a complex of a large pillared porch with four completed cells. On the crown is a large zeolite filled vug. There is a potential zone of rockfall in the right aisle. **The treatment suggested includes filling up of potholes and pools upto the waterfall in the major nala above cave 5, lining of the central 5 m of the nala channel over which perennial flow is observed,**

provision of an iron barrier 20m from the edge to catch rolling boulders, reinforced shotcrete with galvanized wire below cave and rock bolting of loose block in the right block.

- 78 The outer 3-4m of CAVE 6 has collapsed. Cave 6 is different architecturally from other caves. It consists of a central hall, which leads to an antechamber and shrine. On the sides of the central hall are two side halls. At least two pillars, which were supporting the crown at the outermost extremity, have collapsed. The outer wall of the right hall and part of the crown has collapsed at two different levels along two unit contacts. Casts of ropy structure can be seen on both surfaces where roof collapse has taken place. The crown of the central hall that is higher than the two side halls shows trace of unit contact and shows a category 5 fracture. The trace of the crack can be seen in the window recess and the walls. This crack can be seen day-lighting on the outer wall. A major zone of de-slating has been created on the outer side due to this sub-vertical crack and this is being monitored using mechanical demag. **The treatment suggested includes plain shotcreting and rock bolt above cave 6 and construction of a suitable structure to provide support from below. This should be designed in consultation with a structural engineer.**
- 79 CAVE 7 is situated below cave 6 and the centerlines of both the caves fall on the same axis. Outside the hall there must have been an outer verandah, which has now perished. In the outer 3-5m all structures have collapsed. The cave consists of a huge square hall with cells on three sides. The crown is supported by four square pillars all of modern construction. A large portion of the crown to the right has fallen, along a unit contact. Casts of ropy structure are visible. The crown of the cave bears numerous cracks, some of which are along unit contacts. The category V crack seen on the crown in the hall can be traced on the floor of left hall of cave 6 that is stacked above cave 7. No seepage is seen inside the cave. **The treatment suggested includes shotcreting of the crown of the cave to arrest flaking and load test at the portal**
- 80 CAVE 8 is a vihara, the shrine of which has a circum-ambulatory passage, the only one of its kind at Ellora. It consists of an outer hall with a shrine. The outer hall leads into an inner hall. The inner hall has three cells on the left side. The third cell has a major crack on the crown and walls. The inner hall leads into another hall, at the center of which is a shrine having a walkway surrounding it. There is no seepage in the cave. In the outer hall a zone of de-slating has been created due to displacement along a crack developed along a unit contact. **The treatment suggested includes rock bolting to stabilise the de-slating block.**
- 81 CAVE 9 is a small cave situated at a higher level, above cave 8. It is now approached through cave 6 by a small porch with four pillars and a small passage. Cave 9 consists

of a small open courtyard, the façade of which is decorated with a chaitya motif. A part of the façade above the chaitya motif has broken. **The treatment suggested is to shotcrete the façade and extend it to 5 m from the top. The existing drain should be modified and should be extended down to bedrock level. Construction of a new drain above the existing drain may be necessary.**

- 82 **Cave No. 10** is a Chaitya griha. Its entrance is through a wall, which is in a dilapidated condition. Inside is a square courtyard, on three sides of which are verandahs with porches and cells. The façade of the cave is made up of a 'Chaitya' - opening on the upper deck. Above this is a small overhang decorated with rock cut beams and rafters in imitation of wooden architecture. The overhang is cut across by a westerly dipping crack and unit contact. Seepage is observed at three places from the overhang in the form of droplets. Some of the rafters are damaged. On the lower deck the outer portions of the verandahs and cells show a progressively more weathering. In the cell on the left verandah, some part of the crown has collapsed along a unit contact and the remaining portion is in the process of separation. On the upper deck in the left verandah the highly fractured zone is seen on the crown and a copious amount of seepage is noticed here. In two cells on the right, extensive weathering and seepage are observed. A colonnade of 30 pillars supports the Chaitya of cave 10, which divides the aisles from the nave and apse. The crown of the front aisle is arched. There are no fractures present on the crown. **The treatment suggested includes protection of beam/ rafters on façade by shotcreting and micro-stitching, rock bolting and selective shotcreting on crown of cell on left verandah of lower deck and also part of the verandah near the staircase, selective shotcreting on crown of right verandah of lower deck and cell, micro-stitching of loose rock, repairing of crown of outer two cells on right side of upper deck, removal of old gunited layer and fresh shotcreting up to 15 m from the edge.**
- 83 **Cave 11** is a three-decked cave. The entrance is through a front wall, which has almost entirely perished. The open to sky courtyard is T shaped. On the left wall of the courtyard is an L shaped cell in which numerous cracks can be seen. On the outside chunks of rock have fallen. The lower deck of cave 11 consists of a long verandah having 8 large square pillars. The verandah opens into a shrine in the central part. The crown of the verandah contains numerous category 1 cracks. The middle deck of cave 11 consists of a long verandah, cells and a small shrine. Minor fractures are present on the crown. The upper deck consists of a long verandah. In the central part, the verandah opens into another verandah, which is also rectangular in shape. Inside this is a long rectangular hall. Further inside is the antechamber and shrine. Remnants of original plaster can be seen at many places. In the hall, antechamber and shrine only minor cracks are present. **The treatment suggested includes shotcreting of the façade and**

extending it up to 20 m to the top keeping the existing drain with a new drain at top, shotcreting of the crown of the cell on the left of the courtyard and training of the nala between caves 11 and 12.

- 84 Cave 12 is a three - decked cave with a large T shaped courtyard in front. On the northern side of the courtyard is a cell with a water tank. While on the southern wall is a cell situated at a height of 5m and is in a dilapidated condition. The façade of the top deck is marred by rock fall. On the right side the collapse of the façade/overhang is along a highly fractured zone through which seepage in the form of a continuous drip is seen. At the landing between the middle and upper decks, seepage is seen from the crown of the staircase. Seepage is also seen in the cell on the southern side of the cave at the landing between the lower and middle decks. The top deck consists of a large rectangular hall. The hall is divided into five sections by four colonnades, each of eight pillars. An antechamber leads to the shrine. At a few places small parts of the crown have collapsed. The middle deck consists of a verandah and a large hall inside. On the sides of the hall are numerous cells. There are no fractures in any of the cells, which are mostly covered by original plaster. Only minor category I and II cracks can be seen on the crown of the middle deck. The bottom deck of cave 12 consists of a large hall divided into a number of aisles by rows of pillars. A large antechamber leads to a shrine. On the sidewall of the antechamber as well as the halls are a number of cells. Treatment measures suggested include rock bolting and reinforced shotcreting of the façade in the top most part, discharging of the upper drain into the nala, plain shotcreting on the rock ledge on either side, boulder packing and shotcreting in cavities along the fracture zone on the rock ledge.
- 85 Cave 13 is a small rectangular cave without any ornamentation. The outer structures appear to have been destroyed. The right side of the entrance is somewhat intact while the left side is broken. A few cracks falling in category III are seen on the crown of the cave. The floor of the cave is covered by residual soil (?) attesting to grade VI of weathering. Seepage noted is in the form of moist patches on the inside of the front wall on the left side. The unit contact serves as the conduit for surface run-off to seep inside. Treatment measures suggested include reinforced shotcrete with provision of drainage holes in the negative slope above caves 13 and 14, plain shotcrete below cave 13, shotcrete above caves 13 and 14, which to be extended for 20 m on top, top drain to be constructed and end of shotcrete discharge to be led to nala above 14, training and lining of nala.
- 86 Cave 14 is a small cave consisting of a hall with four aisles surrounding it, a shrine with a walkway around it. The outer 4-6 m of the cave may have contained some structure, which has perished. Cracks falling in categories I to III and trace of squeeze up structure are seen on the crown. Seepage of water in the cave is restricted to the

outer beam. The façade of cave 14 can be divided into 3 zones. The lowermost zone just above the crown of the cave consists of moderately weathered basalt. The middle part shows development of negative slope due to differential weathering along a highly fractured zone. Seepage is observed through the fractured zone due to infiltration from the ground surface (where the fractured zone crops up). Above this lies the moderately weathered basalt. On the roof of the cave, water from a nala is directed to the side of the cave by a channel. This channel is blocked at the end and results in ponding of water, which then overflows over the façade.

- 87 Cave 15 is situated at a higher level and is approached by a flight of steps. Inside the cave complex is a courtyard with a square 'mandapa' in the center. The crown is moderately weathered where flaking is observed at places. There are two cells on either side of the 'mandap' on the walls of the courtyard. In the cell on the left fractures are seen on the crown, through which seepage is taking place. The cell on the right has almost entirely perished, with most of the crown and sidewalls having fallen. On the right wall of the courtyard is a complex, consisting of water tanks and a cell situated above. The crown of the cell is highly fractured and at a few places the rock has collapsed. The seepage is in the form of droplets. The facade of cave 15 which is a double decked cave is marred by rock collapse and weathering. The highly fractured zone cuts across the façade. The lower deck consists of a T shaped hall divided into three parts by a row of pillars. Minor cracks, traces of squeeze up structures and geodes can be seen on the lower deck. The upper deck is much larger than the lower deck. On the upper deck seepage is seen in the form of moist patches/droplets near the 2nd pillar of the 5th beam. Remnants of paintings are seen. Minor fractures are present. **Treatment measures include boulder packing and plain shotcreting on the rock ledge on both sides of the staircase near and outside the entrance, shotcreting of the façade to increase strength, with provision of drainage holes, extending the shotcrete along the hill slope up to the foot track to Khultabad and cleaning , widening and lineling of existing drain situated on the up-slope side of the foot-track. All the drains should be embedded in fresh bedrock and windows are to be left on the hill slope side to collect seeping water.**
- 88 Cave 16, which is known as the 'Kailash' – Lord Shiva's mountain abode is the largest and the best of all Ellora excavations and is, considered to be the finest monument in India.
- 89 The sculptures on the west-facing wall on either side of the entrance appear to have suffered more weathering due to westerly winds and exposure to sun.
- 90 The Kailash temple, situated in the center of cave 16, at a higher level, consists of a central hall flanked on three sides by verandahs. In the verandah on the right the outer portion of the floor is broken. The crown shows two fractures falling in category 5. In

the olden days there was a bridge connecting the right verandah of Kailash temple to the second deck of Pad Lanka. This bridge has collapsed. The cracks seen in the crown of the right verandah are probably related to the collapse of the bridge. The cracks have divided the crown into three parts. In the left verandah and the front verandah, minor category I fractures are present.

- 91 Surrounding the Kailash and cut into the scarp is a pathway known as the Parikrama, consisting of a narrow verandah like excavation supported by numerous pillars on three sides and recessed into the scarp. A portion of the overhang has collapsed along a unit contact on the right side. Another square block at the right corner has become detached and has already shifted a few millimeters. On the left corner also a portion of the overhang has collapsed. Some portions have become detached and are on the verge of collapse.
- 92 In the central portion of the right face of cave 16 is a four-decked complex known as 'Pad Lanka'. The first (bottom) deck of 'Pad Lanka' consists of a verandah and a partially excavated hall. Numerous fractures can be seen on the crown. The second deck of 'Pad Lanka' consists of a verandah and a large hall inside. The floor of the deck extends outwards. The thickness of the floor is about 1m. The floor of the second deck may have extended and connected to the right verandah of Kailash temple. On the side of the stairway two pillars have been constructed to support the crown of the first deck. At the junction of both the pillars and crown there is a small gap and the load is supported at only one or two points. The gaps should be properly packed to ensure even distribution of load. The third deck of the 'Pad Lanka' consists of a rectangular verandah and an inner hall. The verandah leads into a rectangular hall. Four pillars with double arched beams support the crown. The central part of the crown has been cut to form a skylight. The entrance to the fourth deck is from the hill slope on the right side of the cave. Extensive weathering has taken place along the unit contact and heavy seepage is reported. Apart from this, portions of the crown have collapsed along unit contact. At a few places some portions of the crown are precariously poised. Four pillars having double arched beams support the weight of the overlying rock mass. All the four beams have developed cracks that are vertical and reach up to the unit contact lying above. The fourth deck of this complex can be approached by the foot-track on the right of cave 16, leading to the village of Khultabad. It consists of a square hall, the crown of which is supported by four pillars.
- 93 To the left side of the cave 16 (cave 16/ 4 and 5) complex and situated at a higher level and approachable by a flight of steps cut into the hill slope, are two small caves with shrines, excavated side by side. The caves are in a general state of neglect and in a dilapidated condition.
- 94 The treatment suggested includes reinforced shotcreting with rock bolts in the

NW corner above the verandah having images of Ganga, Jamuna and Saraswati; removal of loose blocks in the NE corner of the Parikrama; rock bolting of loose blocks in the overhang of the parikrama (Vertical bolts); removal of the half-constructed pillars in Pad Lanka; rock bolting of rock mass to the east of Pad Lanka (Horizontal bolts); shotcreting of the crown of the verandah on the left of the entrance (on the front wall and approached from the inside) pressure packing of the gap between the pillars and crown of first deck of Pad Lanka; removal of the old and crumbling gunited surface on the hill slope on the southern side of the cave and shotcreting the surface; repairing the gunited surface on the northern slope wherever necessary; shotcreting of the excavated area to the east of the eastern cut face; smoothening of the ground with a gradient towards south to drain the water; treatment of the drain carrying water along the hill slope by lining of the channel and diversion of the channel down slope, through a steel pipe to stop infiltration.

- 95 For caves 16 A, B, C, the treatment measures include extension of surface shotcrete upto 5 m from the top upto the base of the scarp; providing a drain at the base of the scarp all along, to divert the collected water to the nala north of the cave and to divert flow towards the northern part of the nala by filling up the depressions.
- 96 CAVE 17 consists of a courtyard, hall, and shrine. In left side cell, cracks and heavy seepage and evidence of rock fall are observed. A masonry column has been constructed to prevent rock fall. The rock mass in the cell is highly weathered. The facade is also slightly weathered and shows open cracks. Seepage is observed from these cracks. **The pillars and roof need treatment to avoid any further damage.** The pillar present on left side of courtyard is highly damaged. Rock inside the hall is fresh and unweathered. Sculptures present on left and right wall near entrance of shrine are damaged.
- 97 CAVE 18 consists of a courtyard, a central hall and the shrine. Facade is in broken condition. Left side, front wall and column indicate intrusion of quartz vein. Crown of hall shows indication of seepage. In the central hall the rock is unweathered.
- 98 CAVE 19 : The front wall that supports the rock load has developed major fractures whereas the facade is in dilapidated condition. The Central hall is supported by a row of rectangle shaped columns in which the first row of column is completely destroyed and 1st column to the left has developed major fractures and is in a highly weathered condition. The 2nd column to the left side and first two columns on the right are half constructed cement concrete columns. Number of fracture planes / joint planes are present on the crown of hall. Seepage inside the cave is because of infiltration from the drainage channel situated on the left side near the entrance of the cave. Front portion of the crown of hall is highly weathered. Evidences of rock fall are imminent.

- 99 CAVE 20 consists of a courtyard, verandah and a hall. There is no statue or sculpture inside the cave. The facade shows seepage. Seepage in the form of drops is observed from a vertical crack in the verandah. The only sculpture on front wall to the left of courtyard has lost its sharpness due to weathering and is damaged due to development of cracks. Basal 0.3m portion of cave is slightly weathered as compared to rest of unweathered portion of hall and verandah.
- 100 CAVE 21 consists of a courtyard, a hall, and the shrine. Courtyard contains a pillared porch each on the left and right sides. Six ornamented pillars support the crown of cave. Central hall is of rectangular shape with one pillared cell each on left and right sides. Encrustation of calcium carbonate is observed in the corners of hall. The rock mass of chabutra (Nandi portion) is slightly weathered and the sculptures have lost their sharpness and are partly damaged because of weathering. Seepage in the form of continuous dripping is noticed from crown portion on the right-pillared porch in the central hall.
- 101 CAVE 22: The entrance of the cave is in a dilapidated condition. The rock is weathered and fractured. Cave consists of a courtyard, a central hall, an antechamber and the shrine. There is a cell each on left and right sides in courtyard. Few category II and III fractures are observed on the left and right-pillared porch of the central hall. The left aisle of the central hall shows seepage on the front wall side. Seepage is also noticed on the right cell of the central hall along a vertical crack in the crown portion and from a horizontal joint above the left cell in the courtyard. **Surfaces above the left cell need to be treated.**
- 102 CAVE 23 consists of a courtyard and four cells in a row. There is a cell with a hall, on the right. The cells, which are in rows, indicate a stable roof without any fractures whereas the cell on the extreme left is in a dilapidated condition, the two pillars of which need immediate treatment. Wall between 1st and 2nd right shrine is having a large hole. Seepage in the form of drips is noticed from the left corner of the shrine cell. Rock mass of this cell is moderately weathered.
- 103 CAVE 24 and 24A: These two caves with a common wall, consist of verandah and shrine. The crown of verandah contains fracture / valley relief joint and seepage is noticed. **This fracture needs immediate treatment.** Seepage is noticed in the form of continuous dripping from right unfinished cell.
- 104 CAVE 25 consists of courtyard, verandah, left and right aisle, antechamber and shrine. All 6 pillars in the courtyard have been destroyed. The overhang portion in courtyard is unsupported and has developed many cracks. Outside the cave towards right, there is a water tank having a depth of 3.30m and 11.40 x 5.40m length and breadth, which should be covered / filled with concrete to prevent any accident. Seepage is mainly

from and the crown of verandah. A highly fractured and jointed portion is noticed in the left and right side of facade where rock mass may fall in near future. Nandi in courtyard has been extensively damaged and only the basal portion is preserved.

- 105 CAVE 26 consists of a central hall, supported by rectangular ornamented pillars and a shrine. Highly fractured, jointed zone is observed on right side facade of cave above the water tank which may lead to rock fall in future. Rock inside the cave is unweathered. Right side front wall of central hall indicates plastering of wall, which has peeled off from most places.
- 106 CAVE 27 has triple shrines on the rear wall and sidewalls of its mandappa. This cave consists of 4 octagonal columns supporting the facade and connected to central hall and shrine. The facade of a cave is stable except towards right side where the small jointed and fractured portion is to be removed and or treated accordingly. The crown portion of central hall in front of left cell shows weathered unit contact with fractures. Seepage is noticed from facade of cave in form of droplets. Rock inside the cave is slightly weathered.
- 107 CAVE 28 is excavated approximately at the middle of 37m section. A nala draining on top of hill forms a waterfall just in front of the cave. A small foot-track leads upto cave 28 and continues with a flight of stairs upto cave 29. Cave 28 is an incomplete cave and consists of courtyard and shrine. **Horizontal joints along unit contacts are open and require treatment.** The floor of cave is uneven rocky surface.
- 108 CAVE 29 consists of courtyard, central hall, and shrine. Four cells are present on the left hand side, outside of courtyard where the rock mass on the sloping ground in overburden has developed open joints which has to be removed or slope stability measures are to be taken up to prevent any damage to the cells. Central hall consists of two rows of rectangular pillars and three aisles each on left and right side. Distress cracks are observed in some of pillars. Dripping of water is noticed in the facade open passage of cave. Locally, waterlogging conditions are observed in a narrow open portion in front of pillared porch. In the porch there are six pillars in a row which are in a highly damaged condition. Rock fall of rolled boulders is noticed in the open narrow passage.
- 109 CAVE 30 is excavated within the hill where the high standing wall of 15 meter is present in the back side of temple, because of which the drained water along the hill slopes accumulates and locally water logging conditions are noticed within the left porch and peripheral portion of the cave. This cave consists of a carved rectangular entrance, a courtyard, central hall, and Shrine. There is one cell each on left and right side of the Central hall. Near entrance, the cave on its right side has developed a horizontal fracture with open joint, and the blocks may dislodge any time. Rock at entrance is highly weathered and vesicular in nature. Seepage is noticed from the fracture

of category 5 present in the crown of entrance and left corner of central hall. Major damage is towards outer left portion where a part of facade has fallen. Pillars inside the cave are moderately weathered at the base. Sculptures on outside walls of cave are moderately weathered and damaged due to micro-fractures and weathering. **Some chemical treatment is required for cleaning the weathered moss covered portion outside the cave.**

- 110 CAVE 31 consists of small rectangular hall and a shrine. Two major fractures of category V run across the hall. Seepage is noticed along these fractures. **Facade of cave consists of highly jointed rock mass and requires treatment.** Rock is moderately weathered outside the cave. Relief joint observed on a sloping ground in facade and above the cave, lead the infiltrated water from top weathered zone and soil cover, to the inside of cave.
- 111 CAVE 32 is a two-decked temple similar in plan to cave 16. A fracture of category V with seepage is noticed on the crown of the 1st left cell. Seepage is noticed from a hole in the crown near 1st right pillar. Right side 1st cell on courtyard is an incomplete excavation where a fracture of category V is observed. Seepage is noticed. A crack of category IV is observed in the crown portion of central hall. A flight of stairs in right side of verandah of ground floor leads to the upper deck. It consists of central hall, and small entrances with cells each on left and right side connecting to pillared complexes. Seepage is observed inside the cell adjacent to the hall. Facade of right side complex is weathered and fractured. Seepage is also noticed. The rock is moderately weathered. In left complex a crack of category III with water is observed.
- 112 CAVE 32B can be approached by stairs from the right side of cave 31. This cave consists of a courtyard, hall and shrine. This is an incomplete cave where unfinished excavations are present on both left and right side of the hall. A fracture of category V and seepage are noticed.
- 113 CAVE 33 is a two-decked cave. In the central hall of ground floor a major quartz-jasper-flint vein is observed. A number of cracks of category III to V with seepage are observed on the crown of central hall. Upper deck consists of 4 aisles, central hall, shrine and incomplete cells. Crack of category V is noticed in the corner of right aisle where seepage is noticed.
- 114 CAVE 34 consists of a courtyard, a verandah, a central hall and a shrine. Wall between caves 33 and 34 is broken. Facade is highly jointed and has developed many cracks. Rainwater accumulates in the right hand corner, near entrance where water tank is present. Crown of central hall indicates cracks of category V. The rock is slightly weathered.
- 115 Environmental studies were carried out with the objective to assess the status of existing

environment and to suggest mitigatory measures for the negative impacts on the monuments. Parameters covered under the present studies include:- micrometeorology, ambient air quality, water quality, noise levels, ambient temperature and humidity inside the caves, impact of developmental activities etc. The data was generated/collected during the period from January to December 1999.

- 116 Data on meteorological parameters such as *temperature, relative humidity, wind speed and wind direction and rainfall* was generated by installing maximum and minimum thermometer, maximum and minimum humidity recorder and rain gauge and also by observing the seasonal variation in wind direction.
- 117 The prevalent wind direction was observed from January to December 1999. Prevalent wind direction for the month of January to March was northerly and northwesterly. During the months of April to September the wind direction was westerly and during the month of October the wind direction was bi-modal and the prevalent directions were easterly and northeasterly. During the months of November and December the prevalent wind directions were northerly and north- westerly.
- 118 During the winter months the mercury touched a low of 10°C whereas it reached a high of 44.1°C in summer months.
- 119 During the year 1999 the area received only 512 mm of rainfall during the monsoon season, which is much lower than the average annual rainfall.
- 120 At Ellora, humidity was measured throughout the year and minimum and maximum humidity were recorded for each month. During the winter it varied from 24% to 89% and during summer its range was between 13% and 99%. During monsoon, the range was from 31.4% to 99%.
- 121 The flora of the area represents tropical deciduous scrub forests. This is a degradation stage of dry deciduous forest and is continued to areas with poor soil and steep slopes. The species exhibit various stages of transition from tree forests to scrub forests.
- 122 Air monitoring was carried out to assess the air quality of Ellora caves area and its impact on monuments if any and to suggest appropriate control measures.
- 123 Near cave 16 higher values of Respirable Particulate Matter and Suspended Particulate Matter were recorded during the months of February, March and April 1999. Near cave 15, SPM and RPM values are above the permissible limits of 100 and 75 mgm/m³ in the months of March and April. Near cave 32, SPM and RPM values are less than those at cave no. 16 and 15.
- 124 To know the water quality of Ellora caves area, 6 numbers of stream water samples, 13 numbers of storage tank water samples and 7 numbers of seepage water samples from caves were collected for major oxides and toxic elements determination and for carrying out bacteriological test. Water from storage tanks in cave nos.11, 12, 15 and 29 and

streams near caves 5, 16 and 29 are not potable.

- 125 Chemical analysis of 25 samples for 23 parameters collected during two seasons i.e. winter and summer and seepage water in the rainy season, shows that the major mineral constituents and toxic metals are well within the permissible limits as assessed against IS 2296 (Class 'A' water). Storage tank water of cave 34 during winter and summer shows pH value of 5.90 and 3.60 that indicates that it is acidic in nature.
- 126 Cave nos. 2, 10, 8, 16 suffer the most from noise pollution as compared to the caves which are open i.e. 1, 6, 12 and 32.
- 127 Temperature and humidity were recorded in all the 34 caves at Ellora. Seventeen caves were selected for the comparative study considering their size, shape, location, elevation, type and paintings. The selected caves include cave nos. 1, 2, 5, 6, 10, 12, 14, 16, 17, 19, 19 B, 21, 25, 29, 30, 32 (upper deck) and 34.
- 128 During environmental impact study due to the tourist influx and developmental activities on the caves' environs, following impacts have been identified and keeping in view the sanctity and aesthetics of the monuments, the following mitigating measures are suggested.
- 129 Average RPM and SPM values for the year 1999 near cave no. 16, 15 and 32 are 52, 87, 53, 75, 46 and 78 respectively are within the permissible limit of 75 and 100 mgm/m³. Parking place for tourist vehicles may be shifted to a place at least 1/2 km away from the caves and preferably to the left side of Aurangabad – Ellora road and should be tarred. In order to check the deterioration of air quality due to this, the feasibility of planting tall growing trees by the side of road leading to caves to act as natural receptors to the particulate matter may be examined. To reduce concentration of particulate matter in the area removal of grass in the cave confines and grazing should be prohibited. Turfing /paving or small garden may be developed in front of the entrance of cave 16 to arrest the blowing of sand as particulate matter during dry season. Removal of the topsoil from the cave confines, which creates negative visual impact and leads to soil erosion by wind and water, should be stopped and area should be suitably afforested. Noise levels in the parking area are too high during peak hours, which are above the prescribed limits for sensitive zones, hence the area may be declared silence zone. The water stored in storage tank of caves should be periodically treated. Safe potable water may be made available at the caves by extending the existing water supply line. Use of water storage tank for drinking purpose should be stopped. Water vending machines may be installed at 5 to 6 places. The entire area of cave from 1 to 34 should be suitably fenced and entry of stray animals should be stopped. Foot track on the left side of cave 16 leading to the top of cave 16 is in bad shape and should be rebuilt. A toilet near caves 1, 21 and 32 on the lower valley slopes may be constructed with proper and effective waste disposal system. Proper garbage collection and its disposal

away from the caves' environ should be brought into practice. Polythene packs seen scattered along the slopes cause negative visual impact and pollute stream water. A foottrack leading to cave 25 from cave 24 is in bad shape, which should be properly guarded by railing. Railing by the sides of cave opening of cave 16 on the top on 3 sides should be made for public safety. Foottrack from the left side of Khultabad to Cave 16 should be guarded by railing on the roof-top of cave 15 or from the left side of foot track near cave 15. To reduce ground vibrations, entry of heavy vehicles upto the gate of cave 32 should be banned. A R.C.C. structure constructed for office between cave 16, and 15 should be removed.

- 130 To overcome the negative impacts identified during the course of studies on caves' internal environment on account of the tourists influx, a series of mitigating measures are suggested: All the entry points should be covered with wire mesh, polygrass, astroturf's etc., upto suitable lengths. Vacuum cleaning twice a week should be sufficient to remove the dust from the caves. Use of caves for storing building material such as cement, chemicals etc. should be avoided. To keep the noise levels within tolerable range, people should be cautioned by proper guidance and suitable and sufficient display of posters/ pamphlets at entry points especially at caves 10, 16 (main temple), 32 (top deck) and 34 (top deck). The entry of vehicles upto the cave 10 should be stopped. To minimize humidity, suitability of installing humidity control equipment should be explored. Bats are nesting in cave 5, 12, 16, 19, 25, 29, 30 and 32. These caves should be covered with doors/wire mesh after driving off the bats or sufficient lighting arrangement inside the caves should be made. Existing railing at Chikni Lanka (cave 16) should be extended up to the next wall. Water storage tanks inside the cave nos. 10, 11, 12, 17 and 27 should be covered. Stairs of cave 16 should be repaired and lighted properly. Similar measures should be taken for the stairs of Chikni Lanka.

